URBAN OZONE AND THE CLEAN AIR ACT: Problems and Proposals for Change

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URBAN OZONE AND THE CLEAN AIR ACT:
Problems and Proposals for Change

A Staff Paper
from OTA's Assessment of
New Clean Air Act Issues

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PREFACE

Over the past several months, Congress has once again turned its attention to the widespread failure of U.S. cities to attain the health-based air quality standard for ozone. The last major set of changes to the Clean Air Act, the Clean Air Act Amendments of 1977, set December 1987 as the latest deadline for attaining the standard. Last December, as many urban areas faced the prospect of sanctions, Congress extended the deadline through August, allowing more time to consider several proposals addressing the ozone nonattainment problem. This OTA staff paper has been prepared to assist the ongoing Congressional consideration of these proposals.

S.1894, a comprehensive set of amendments to the Clean Air Act, has been reported by the Senate Committee on Environment and Public Works and awaits consideration by the full Senate. H.R.3054, introduced by Congressman Waxman and 39 cosponsors, is currently being discussed within the Subcommittee on Health and the Environment of the House Committee on Energy and Commerce. EPA has proposed its "post-1987" ozone policy in the Federal Register, stating its plans for implementing the existing Act's mandate to attain the ozone standard in case the August deadline passes without further Congressional guidance.

This OTA staff paper was written in response to separate requests by the Senate Committee on Environment and Public Works and 34 Senators, asking for more information about S.1894 and EPA's proposed post-1987 ozone policy. The staff paper is part of a larger, ongoing OTA assessment of the ozone nonattainment issue, requested by the Senate Committee on Environment and Public Works and the House Committee on Energy and Commerce.

The staff paper contains five chapters:

1. Summary findings and conclusions.

2. The effects of ozone, including discussions of the *health effects* of ozone, current *exposure* to ozone concentrations above the standard, and the effects of ozone on *crops and trees*.

3. Ways to control ozone, including analyses of the *effects of emissions reductions on ozone concentrations*, the *sources of the pollutants that lead to ozone formation*, the *likelihood of attaining the standard with reductions possible from existing control techniques*, and the *costs of controls*.

4. A history of efforts to control ozone since the Clean Air Act Amendments of 1970, focusing on the last major reauthorization in 1977, and *why efforts since 1977 failed to bring more areas into attainment* with the ozone standard.

5. A comparison of the three leading proposals addressing the ozone nonattainment problem.

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1. SUMMARY

Summarized below are the key findings and conclusions of our staff paper:

Human Health Effects

o Ozone has been shown to cause immediate, short-term changes in lung function and increased respiratory symptoms. There is ample evidence that some healthy adults who exercise heavily for one to two hours during periods of elevated ozone concentrations (greater than 0.18 ppm) experience pronounced symptoms (such as cough and pain on deep breathing) and significant decreases in lung function. A number of new studies show some temporary reduction of lung function among moderately to heavily exercising children and adults exposed for one to two hours to ozone concentrations comparable to peak levels found in many nonattainment cities (0.12-0.16 ppm). Short-term decreases in lung function and increased respiratory symptoms have also been shown to occur in healthy, exercising individuals exposed for prolonged periods to ozone as low as the current standard level of 0.12 ppm. Some researchers have expressed concern about effects occurring at ozone concentrations between 0.08 and 0.12 ppm among people exposed for up to six hours. The long-term implications of these short-term changes are uncertain.

o Ozone has been suspected of playing a role in the long-term development of chronic lung diseases. While not dismissing the short-term effects of ozone, many health professionals appear to be more concerned that repeated exposure to ozone over a lifetime may result in permanent impairment of the lung. New epidemiologic research suggests that accelerated rates of decline of lung function with aging occur among residents of communities with high ozone concentrations. Clinical studies of humans have recently shown that prolonged exposure to low ozone concentrations results in progressively larger changes in respiratory function and symptoms with time. Animal studies have shown that prolonged ozone exposure can cause biochemical and structural injury to the lung. Some of these changes are suspected of playing a role in the development of chronic lung disease, although inherent uncertainties in extrapolating from animal data make it difficult to assess human risk from these studies. Together, these studies suggest that there may be some persistent effects associated with long-term exposure to ozone. However, at this time our understanding of the contribution of ozone to the development of chronic lung disease is limited.

o Two groups have been identified by EPA as being potentially at increased risk of developing adverse health effects when exposed to elevated ozone concentrations: 1) a subgroup of the general population with preexisting respiratory disease (e.g. asthma, chronic obstructive pulmonary disease), and 2) those individuals who exercise or work outdoors. The first group is of concern because their respiratory systems are already compromised. The strongest evidence of increased risk exists for people who exercise heavily outdoors. They are at risk because the doses they receive are high due to their increased breathing rate. EPA also estimates that about 5 to 20 percent of the healthy population may represent a subgroup of "responders" who may be significantly more responsive than the general population to the same dose of ozone.

Exposure to Ozone

o Based on 1983-1985 ozone data, 76 areas (encompassing 94 individual metropolitan statistical areas (MSAs) and 10 non-MSA areas) are in violation of the health-based National Ambient Air Quality Standard for ozone, which allows no more than one exceedance per year (on average over three years) of a daily maximum one-hour average ozone concentration of 0.12 ppm. Approximately 130 million people reside in the 76 areas.

o Based on hourly ozone data for the period 1983-1985, and taking into account people's daily activity patterns (e.g. when and where they are indoors and when and where they are outdoors) and exercise levels, we estimate that about 35 million people -- 25 percent of the people who reside in nonattainment areas -- are exposed to ozone concentrations above the standard for at least one hour each year. Nationwide, more than 10 million people are estimated to be exposed to concentrations above the standard while exercising at moderate to heavy levels of exertion.

o Outside of the Los Angeles area, people who are exposed to ozone concentrations above 0.12 ppm during normal activities (i.e., not exercising) are exposed for an average of about 4 hours per year. People who live in the Los Angeles area and are exposed to ozone concentrations above 0.12 ppm during normal activities are exposed for an average of more than 20 hours per year.

Effects of Ozone on Crops and Forests

o At many locations throughout the southern and eastern halves of the United States, rural ozone concentrations are high enough to reduce yields of economically important crops by 1 to 20 percent compared to yields that would be expected if ozone concentrations were at natural background levels. The most heavily affected crops include soybeans, wheat, cotton, and some types of produce. Agricultural benefits of about $2 billion would be anticipated if rural ozone concentrations could be reduced by 25 percent.

o Ozone causes foliar injury and reduced growth rates in sensitive trees of several species. Exposure to ozone can lead to increased susceptibility to diseases and other stresses, increased mortality of individual trees, and eventually to overall decline of affected species. All of these effects of exposure to ozone have been observed in forests in the mountains bordering the Los Angeles basin. Ozone damage has also been observed in ponderosa and Jeffrey pine at other locations in California. In the eastern United States, ozone is held to be responsible for widespread foliar injury, reduced growth, and increased mortality in eastern white pine. Ozone has also been suggested as a causal or contributing agent in reported declines or growth rate reductions of red spruce, yellow pine and sugar maple.

Sources of Volatile Organic Compounds (VOCs)

o Ozone is not emitted, but rather is produced in the atmosphere from reactions involving two pollutants: volatile organic compounds (VOCs) and nitrogen oxides (NO_x). EPA has historically encouraged exclusive reliance on VOC emissions controls to meet the ambient air quality standard for ozone.

o Nationwide VOC emissions totaled about 19 million tons during 1985. About 7.7 million tons were emitted in nonattainment areas. Without additional regulations, emissions will decline by about 3 to 5 percent through the mid 1990s, and then slowly rise back to current levels by 2003. Projected VOC emissions reductions from highway vehicles are expected to be offset by emissions growth from small stationary sources.

o Highway vehicles contributed about 30 percent of the total VOC emissions in 1985. Another 30 percent originated from evaporation of organic solvents used in surface coatings, printing, dry cleaning, and for degreasing metal parts and products. About half of the total 1985 VOC emissions originated from small stationary sources that, individually, emit less than 50 tons per year.

VOC Emissions Reductions and Costs

o OTA was able to identify potential emissions controls to lower VOC emissions in nonattainment cities by about 20 percent below current levels by 1993. We believe that the large majority of VOC emissions reductions possible with currently available control methods are accounted for in our analysis.

o The VOC emissions reductions in nonattainment cities in 1993 from each of the nine control strategies analyzed by OTA are as follows:

1. "Reasonably available control technology" (RACT) controls on existing stationary sources: 6 percent;
2. Limits on gasoline volatility: 6 percent;
3. Inspection and maintenance programs for cars and trucks: 3 percent;
4. Federal controls on selected small VOC sources: e.g., consumer and commercial solvents, architectural surface coatings): 3 percent;
5. Stage II gasoline vapor recovery: 3 percent;
6. "Onboard" technology on motor vehicles to capture gasoline refueling vapors: 1 percent by 1993, 3 percent by 2003;
7. Substitution of methanol for gasoline as fuel for centrally-owned highway vehicle fleets: 1 percent;
8. Adoption of new "Control Technique Guidelines" for existing stationary sources: 1 percent; and
9. More stringent tailpipe emissions standards for gasoline highway vehicles: less than 1 percent by 1993, 1 percent by 2003.

o By 1993, after implementation of all the VOC control strategies analyzed by OTA, many nonattainment cities with peak ozone concentrations less than about 0.14 ppm should be able to attain the standard. Areas with more severe ozone problems will be able to significantly lower peak ozone concentrations, but will fall short of attainment. For example, in areas with current peak ozone concentrations around 0.16 ppm, peak concentrations can be lowered by about one-third to two-thirds of the way to the standard by 1993. Areas could come closer to attainment if they are able to implement controls on source categories we were unable to analyze (e.g. transportation control measures). In some areas, controlling NO_x emissions in addition to VOCs would be effective.

o In nonattainment cities, the costs of control strategies analyzed by OTA range between $6 billion and $7 billion per year in 1993, and between $8 billion and $9 billion by 2003. Because some controls would apply nationwide, total costs are about $7 billion to $8 billion per year in 1993, and about $10 billion to $11 billion per year by 2003. The rising costs between 1993 and 2003 are due primarily to the increasing impact of more stringent highway vehicle emission standards.

o The control strategies analyzed by OTA achieve about one-half the VOC reductions needed to attain the standard in nonattainment areas. Because we were not able to identify controls to achieve the other half, we could not estimate total costs to attain the standard.

o The cost effectiveness of most strategies falls between about $1,000 and $3,500 per ton of VOC reduced. "Reasonably available control technology" (RACT) requirements for all stationary sources and substitution of methanol for gasoline as a highway vehicle fuel are the most expensive measures, with cost-effectiveness estimates of about $2,900 to $7,300 per ton of VOC reduced and about $40,000 per ton, respectively. Limiting gasoline volatility is the least expensive measure, at about $320 to $700 per ton of VOC reduced.

Ozone and the Clean Air Act

o The goal of the Clean Air Act is to "protect and enhance the quality of the Nation's air resources." The Clean Air Act Amendments of 1970 established a partnership between the States and the Federal Government. EPA sets nationally uniform air quality standards and the States, with the Agency's assistance, are responsible for meeting them. Of the six "criteria" pollutants for which standards have been established, we have been least successful in our efforts to attain the standard for ozone.

o More than ten years have gone by since the passage of the last major set of amendments to the Clean Air Act. While some progress has been made in reducing VOC emissions and lowering ozone concentrations, more than 60 areas do not meet the ozone standard. As partial explanations for this failure, State and local air pollution control officials suggest that we did not accurately predict the level of emissions control required to meet the standard, and that State-level promulgation of regulations has been hindered by lack of federal support for proposed control measures. EPA officials suggest that emissions inventories and especially projections of emissions growth have been inaccurate, and that the deadlines for attainment established in the 1977 Clean Air Act Amendments were unreasonable. The bottom line, however, is that for a variety of reasons, we have not yet reduced emissions enough to meet the goal of attainment.

Proposals for Change: S.1894, H.R.3054, and EPA's Ozone Control Proposal

o H.R.3054 requires nonattainment areas to meet the standard within 3, 5 and 10 years, depending on the severity of their problem. S.1894 sets a similar schedule for most areas, but allows the worst areas 15 years or longer. EPA's post-1987 ozone policy establishes the longest schedules. Rather than establishing absolute attainment deadlines, EPA sets a schedule for emissions reductions under which some of the worst areas might take over 20 years to attain the standard.

o While none of the proposals alters the Act's ultimate requirement that the standard be attained, each adds interim requirements that may in practice be more important driving forces behind emissions reductions. The most important of these is the requirement for some or all areas to achieve regular increments of emissions reductions, following an explicit schedule in the proposal, or one assigned by EPA. All the proposals require VOC reductions in nonattainment areas of about 25 to 40 percent below current levels by 1993, and impose sanctions if the reductions are not achieved.

o The new proposals also include source-specific technology or performance standards, with S.1894 requiring the most source-specific controls and the EPA proposal the fewest. Some of the specified measures are to be implemented by the States in nonattainment areas only, whereas others are federally implemented controls that apply nationwide.

o All three proposals include provisions for NO_x controls (which, to date, have only been required in California) but with varying degrees of flexibility. Flexibility is an issue because while NO_x controls may be necessary to attain the standard at some locations, controlling NO_x in addition to VOCs at other sites will result in ozone levels that are *higher* than they would have been after VOC reductions alone. The Senate Environment Committee proposal is the least flexible, requiring NO_x reductions from both existing and new sources in all nonattainment areas. The EPA proposal is the most flexible, allowing individual areas discretion to require NO_x controls if they judge them to be helpful.

2. EFFECTS OF OZONE

In this chapter we present a summary of the effects of ozone on human health, a description of population exposure to ozone, and a discussion of ozone's effects on crops and forests. Four major health effects issues are presented, along with a discussion of the impact of ozone on the development of respiratory disease, lung function, symptoms, and susceptible populations. In the exposure section, an assessment of the magnitude and frequency of violations of the ozone standard in nonattainment areas is made, and factors influencing ozone exposure in these areas are described as a prelude to estimates of nationwide human exposure to ozone. Finally, in reviewing the effects of ozone on crops and forests, we discuss ozone concentrations that occur in rural areas; crop yield reductions associated with exposure to ozone at these levels; estimates of the agricultural benefits expected to result from reducing ozone; and potential injury to different tree species due to ozone exposure.

2.1 Effects on Human Health[1]

Human exposure to ozone primarily affects the lungs. Ozone has been *shown* to cause immediate, short-term changes in lung function and increased respiratory symptoms, and has been *suspected* of playing a role in the long-term development of chronic lung diseases. The immediate or "acute" effects may include some breathing difficulty and coughing, but such effects appear to be reversible, usually disappearing after a few hours. Ozone has also been suspected of playing a role in initiating asthma attacks.

Although the short-term effects are important, many health professionals appear to be more concerned that repeated exposure to ozone over a lifetime may result in permanent impairment of the lung. Since ozone damages the tissues lining the airways of the lung, ozone exposure could play a role in accelerated aging of the lung, retardation of lung development in children, or the development of pulmonary fibrosis, a chronic lung disease. However, existing data are just beginning to shed light on questions about the possible long-term effects of ozone exposure. We are not yet able to confirm or dismiss many of the concerns about these effects.

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[1] The following summary of the health effects of ozone is derived largely from a draft report prepared by Lawrence J. Folinsbee for the Office of Technology Assessment.

Major Issues

The debate over health effects from ozone has centered around four major issues: 1) what are the lowest ozone concentrations at which health effects are observed; 2) what constitutes an "adverse health effect" from ozone exposure; 3) who appears to be most susceptible to ozone's ill effects; and 4) what are the effects of exposure to ozone over a long period of time? All of these issues play an important role in the standard-setting process.[2] Determining the lowest level at which health effects are observed is a crucial first step in this process. Studies conducted both in the laboratory and in the ambient environment generate data that help scientists define the lowest observable effects level. Once this level has been determined, a margin of safety is built into the standard to protect the groups most sensitive to the pollutant. The margin of safety is designed to protect these populations against health effects that research has not yet been identified. Deciding which effects are to be considered "adverse" and determining which populations may be most sensitive to ozone are essential to setting an "adequate" margin of safety. Information about adverse effects help policymakers define an upper bound on this margin; information on sensitive populations assist in defining a lower bound. Studies of the long-term effects of exposure to a pollutant also provide input to the standard-setting process. These four major issues are discussed briefly below.

What are the lowest ozone concentrations at which health effects are observed?

The lowest level at which effects from ozone can be observed has been revised downward during the last 15 years, as more information has become available. In the early 1970's the threshold for responses to oxidants[3] was presumed to be 0.25 parts per million or "ppm." This was based on limited data, however.[4] In 1977, new ozone studies showed lung function effects to exercising persons at concentrations as low as 0.15 ppm.[5] During the last five years or so, the health effects data base for ozone has greatly expanded. Scientists now believe that the duration of exposure to ozone and the intensity of exercise during exposure play the greatest role in determining responses at lower levels of ozone. Some of the most significant acute effects have been observed during prolonged periods of exposure (6.6 hours) to ozone and at heavy exercise levels, at concentrations as low as the current standard level of 0.12 ppm.[6] A number of new human studies show that lung function decrements occur in moderate to heavily exercising children and young adults exposed for 1 to 2 hours to ozone concentrations between 0.12 and 0.16 ppm.[7] [8] [9] [10] The prevalence and significance of effects at levels between 0.08 and 0.12 ppm are less clear, and are currently under investigation.

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[2] The air quality standard for ozone is currently under review by EPA.

[3] Photochemical oxidants are a group of chemically-related pollutants. From the standpoint of health and welfare effects, ozone is the most important photochemical oxidant. Ozone typically comprises over 90 percent of the total mass of photochemical oxidants measured in urban air.

[4] Schoettlin and Landau, 1961.

[5] Delucia and Adams, 1977.

[6] Folinsbee et al., 1988.

What is an adverse health effect?

The Clean Air Act directs EPA to set air quality standards for pollutants that may produce "an adverse effect on public health or welfare." A great deal of discussion has been conducted within the scientific and medical community as to what constitutes an "adverse health effect," especially with regard to the effect of ozone inhalation on human lung function at or below the National Ambient Air Quality Standard. While there is general agreement that permanent respiratory injury or episodes of pollutant-induced respiratory illness that interfere with normal activity[11] would be considered "adverse," it is less clear that small changes in lung function indicators or minor increases in the incidence of respiratory symptoms constitute an adverse health effect.

The broad continuum of effects and the diversity of scientific opinion make it difficult to precisely define what is and is not an adverse health effect. The EPA staff recommends that the threshold for an *individual's* adverse respiratory response to acute ozone exposure include *any* of the following responses: (See also Table 2-1.)

- 10 to 20% decrement in FEV_1 in individuals[12] (w/complete recovery after 6 hrs.);
- mild-moderate cough, shortness of breath, pain when inhaling deeply; and
- individual decision to discontinue activity (due to lung function losses and respiratory discomfort).

Most members of the medical community would consider a 10% or greater *group* mean loss in lung function to be sufficient to warrant concern about damage to the lung, especially if one considers that some individuals in these groups are likely to experience greater than average lung function decrements. In addition, lung function losses that may not be harmful

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[7] Linn et al., 1986.

[8] Avol et al., 1987.

[9] McDonnell et al., 1983.

[10] McDonnell et al., 1985.

[11] Ferris et al., 1985.

[12] FEV_1-or the volume of air exhaled in the first second of a forced expiration--is one measure of pulmonary funciton that may indicate obstruction in the lungs.

TABLE 2-1. Grades of Individual Response to Acute Ozone Exposure.

Note: EPA staff recommends that the moderate, severe and incapacitating categories should be considered "adverse" respiratory health effects. All effects in each category are associated with each other.

GRADATION OF RESPONSE	MILD	MODERATE	SEVERE	INCAPACITING
CHANGE IN SPIROMETRY FEV$_1$, FVC	5-10%	10-20%	20-40%	>40%
DURATION OF EFFECT	COMPLETE RECOVERY IN <30 MIN	COMPLETE RECOVERY IN <6 HR	COMPLETE RECOVERY IN 24 HOURS	RECOVERY IN >24 HOURS
SYMPTOMS	MILD TO MODERATE COUGH	MILD TO MODERATE COUGH, PAIN ON DEEP INSPIRATION, SHORTNESS OF BREATH	REPEATED COUGH, MODERATE TO SEVERE PAIN ON DEEP INSPIRATION AND SHORTNESS OF BREATH; BREATHING DISTRESS	SEVERE COUGH, PAIN ON DEEP INSPIRATION, AND SHORTNESS OF BREATH; OBVIOUS DISTRESS
LIMITATION OF ACTIVITY	NONE	FEW INDIVIDUALS CHOOSE TO DISCONTINUE ACTIVITY	SOME INDIVIDUALS CHOOSE TO DISCONTINUE ACTIVITY	MANY INDIVIDUALS CHOOSE TO DISCONTINUE ACTIVITY

Source: Review of the National Ambient Air Quality Standards for Ozone - Preliminary Assessment of Scientific and Technical Information, Draft Staff Paper. U.S. Environmental Protection Agency. Office of Air Quality Planning and Standards. November 1987. p. VII-45.

for people with normal, healthy lungs may be more significant for individuals with preexisting lung disease. Certainly effects that could be incapacitating and could interfere with normal activity (e.g. asthma attacks) should be considered adverse. However, perceptions of what is a medically significant health effect will vary greatly among physicians and patients.

Are there any subpopulations that are particularly susceptible to ozone's ill effects?

In response to the Clean Air Act's mandate that EPA set air quality standards for pollutants, "allowing an adequate margin of safety...to protect the public health," the EPA has sought to identify those subpopulations, if any, that are shown to be more sensitive to ozone exposure than the general population.

Two major groups have been identified by EPA as being potentially at increased risk of developing adverse health effects from exposure to ozone:
1) a subgroup of the general population with preexisting disease (e.g., asthma, chronic obstructive pulmonary disease); and 2) those individuals who exercise or work outdoors.[13] The first group is of concern because their already compromised respiratory systems may be at greater risk than individuals without preexisting disease exposed to the same ozone dose. The second group is at risk because by exercising or working in an outdoor environment, they are increasing the dose of ozone to their lungs. To date, neither of these groups *as a whole* has been clearly shown to be more sensitive to ozone than the rest of the population, although some *individuals* within these groups appear to be more sensitive. The strongest evidence for a population "at-risk" exists for healthy, heavily exercising individuals.

In addition to the above-mentioned groups, studies have shown that there is a subpopulation of otherwise healthy individuals who consistently respond more significantly to the same dose of ozone than do their cohorts. These ozone-sensitive individuals are called "responders." The EPA estimates that from 5-20% of the healthy population may represent a subgroup of responders who are at abnormally high risk to ozone exposure.[14] The factors that would account for such individual variability in sensitivity are unknown at this time.

What are the implications of long-term human exposure to ambient ozone levels?

Perhaps the most important health concern with respect to ozone is the *potential* for irreversible damage to the lung from repeated exposure to ozone over a long period of time.

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[13] EPA, OAQPS Draft Staff Paper, November 1987. While EPA mentions preexisting respiratory disease as a characteristic in the second at-risk group, perhaps the more relevant aspect of this group is that they are exercising, because this will increase the dose of ozone being inhaled into the lungs.

[14] Ibid., p. VI-13.

This is especially critical when one considers that a significant percentage of the U.S. population is living in areas that may experience recurrent episodes of ozone concentrations at or near the national standard. (For further discussion of population exposure to ozone in nonattainment areas, see Section 2.2, which follows.)

Ozone can cause acute decrements in lung function and increased respiratory symptoms in healthy individuals exercising heavily (e.g. competitive running) at concentrations as low as 0.12 ppm. However, while the effects of short-term exposure to this level of ozone appear to be reversible, it is not known if repeated exposure to ozone levels in the range of 0.08 to 0.20 ppm would result in extended or, possibly, permanent changes in lung function or structure. In other words, it is not clear if repetitive exposure to ozone would cause permanent, chronic health effects.

Both animal and human repeated-exposure studies as well as many epidemiological studies have attempted to address concerns about the implications of long-term ("chronic") exposure to ozone. Together, these studies have yielded preliminary evidence that there may, in fact, be some persistent effects associated with chronic exposure. However, estimates of the risks associated with chronic exposures cannot be made with this limited data base.

The Development of Respiratory Disease

Ozone is suspected of playing a role in the initiation or triggering of respiratory disease processes. The evidence that suggests that such an effect is plausible comes primarily from two types of investigations -- animal toxicology studies and human epidemiology studies -- although human chamber studies may also contribute valuable information.

Animal studies

Animal studies have shown that ozone exposure can cause biochemical and structural changes in the lung. Some of these changes are suspected of playing a role in the development of chronic lung diseases. Studies of animals exposed to relatively high levels of ozone (0.50 ppm) have revealed that it may be responsible for at least temporarily reducing the ability of the lungs to clear foreign material and, therefore, to ward off infection.[15] Several studies have shown an increased response to *bacterial* infection in animals exposed to ozone levels as low as 0.08-0.10 ppm for several hours.[16] [17] Continuous exposure to ozone (at 0.50 ppm) has also been shown to alter the course of *viral* infection in mice by leading to structural changes in the lung that increase the likelihood that fibrosis[18] will occur.[19] One type of structural change in the lung which is thought to be linked to the development of lung fibrosis is the deposition of collagen--a structural protein that contributes to "stiffening" of the lung.[20] [21] Repeated, intermittent exposure of monkeys to ozone concentrations as low as 0.25 ppm has been shown to result in increased lung collagen content.[22] Breathing difficulty and subsequent limitation of work performance are characteristic symptoms associated with lung stiffening. Ozone has also been shown to damage certain lung cells in animals at levels as low as 0.25 ppm.[23] However, the long-term health consequences of this cell damage are not known. While many of these studies offer important insights about the effects of exposure to ozone, the inherent uncertainties in extrapolating from animal data make it difficult to assess risk to humans from these studies.

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[15] Foster et al., 1987.

[16] Miller et al., 1978.

[17] Ehrlich et al., 1977.

Epidemiologic studies

Epidemiologic studies have also been used to investigate the potential link between ozone exposure and respiratory disease.[24] One question that has received considerable attention is whether regular exposure to oxidant air pollution causes an increased rate of loss of lung function with age. Part of the normal aging process of the lung involves loss of "usable lung volume," perhaps related to the changes in elasticity of the lung known to occur with aging. (The technical term for this volume is the vital capacity, which is defined as the maximum volume of air that can be expired after taking a full deep breath.) If breathing ozone even at very low levels over a long period of time caused an acceleration of the lung aging process, we would expect to see a more rapid age-related decline in vital capacity in people who reside continuously in oxidant-polluted areas. One epidemiological investigation suggests that an accelerated rate of loss of lung function over a long period (e.g. five years) occurs among residents of high oxidant communities.[25] The evidence is far from conclusive, however, and the question of what impact ozone may have on lung function over a lifetime requires further evaluation before a definitive answer can be reached.

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[18] Pulmonary fibrosis results from the formation of excessive amounts of protein fibers that stiffen the lung. If this stiffening is severe enough, it can produce debilitating disease.

[19] Jakab, 1988.

[20] Last et al, 1979.

[21] Bhatnagar et al, 1983.

[22] Tyler et al, in press.

[23] Crapo et al, 1984.

[24] Epidemiologic studies involve large groups of people who are exposed to oxidant air pollution (mostly ozone) in their daily life and who may experience a variety of adverse responses from this exposure. The kinds of responses that are examined include changes in lung function over many years, the rate of occurrence of asthma attacks, the rate at which people with pre-existing lung disease are admitted to the hospital, and even the death rate from lung or other diseases.

[25] Detels et al., 1987.

Human chamber studies

Prolonged acute exposure (up to 6.6 hours) of humans in controlled laboratory settings to ozone concentrations similar to those found in many nonattainment cities (0.12-0.18 ppm) have had several effects, including: progressively larger changes in respiratory function and symptoms with time[26] and increased responsiveness of individuals to inhaled substances.[27] The relationship between short-term changes in the lung and the progressive development of chronic structural and functional damage is not known. Some health professionals postulate that the link between acute and chronic effects is the lung inflammation observed in the animal and human subjects of short-term ozone studies. Before this inflammatory response disappears, some suggest that it may induce other changes in the lung that might persist over time. Airway inflammation is also a feature of the development of a number of respiratory diseases, most notably asthma and chronic bronchitis.

Issues of susceptibility and adaptation from prolonged exposure

Both animal studies and clinical chamber studies of humans have been used to investigate the effect of repeated exposure to ozone over an extended period of time (over several months in animal studies, over several days in human chamber studies). The importance of such studies is that they help us understand the longer-term effects of ozone on the lung -- i.e., whether or not prolonged exposure to ozone makes individuals more susceptible to subsequent exposure to ozone and other pollutants and whether or not lung function effects are reversible once exposure to ozone ends. Chamber studies of humans show two notable responses to repeated ozone exposure: 1) when an individual is exposed to ozone on two consecutive occasions separated by less than 48 hours, the second exposure generally causes greater lung function effects than the first one[28] [29] and 2) with continued exposure, these effects begin to diminish in intensity and after four or five days the pulmonary function effects are undetectable.[30] [31] [32] This gradual loss of functional response has been called "adaptation."

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[26] Folinsbee et al., 1988.

[27] McDonnell et al., 1987.

[28] Folinsbee and Horvath, 1986.

[29] Bedi et al., 1986.

[30] Horvath et al., 1981.

[31] Kulle et al., 1982.

[32] Linn et al., 1982.

The adaptive responses of individuals who live in areas with high ozone levels might be different from the responses of subjects exposed to ozone for only a few consecutive days in a laboratory setting. Recent preliminary evidence indicates that people who live in Los Angeles may become less sensitive to ozone during the entire "smog season" but regain their sensitivity during the relatively smog-free winter season.[33] In this study, "adaptation" did not disappear rapidly, as in the chamber exposures, but appeared to persist for at least 2-3 months after the end of the smog season. Although this suggests that processes other than those observed in a chamber may be involved in long-term adaptation to ozone exposure, further evaluation is needed before a definitive answer can be reached.

Though measurable lung function changes and symptom responses may lessen for a period, other changes within the lungs are ongoing. In other words, the process of lung injury and repair is a continuous one.[34] Individuals who, through adaptation, experience fewer or less severe symptoms, may be at increased risk since they may be more able to tolerate exercise outdoors during peak ozone episodes, and, hence, receive potentially greater tissue damage over the long-term. Research on animals shows that some lung injury may continue during an "adaptive" period (e.g. effects on host defense system[35] and increased susceptibility to disease[36]), even though other measures of response may be reduced.

Lung Function Effects

Ozone has well-documented short-term, reversible effects on lung function. In studies of people exposed to ozone, the most commonly measured lung function effects are changes in "forced expiratory volume" (FEV)[37] and "forced vital capacity" (FVC). Ozone can cause decreases in both of these measures of lung function.

Changes in lung function depend upon the dose of ozone that is ultimately delivered to the lung. A number of factors influence dose, including the concentration of ozone in the air, duration of exposure, and the average volume of air breathed per minute, referred to as the ventilation rate. The ventilation rate increases with exercise intensity. Figure 2-1 describes the dose-response relationship between ozone and FEV_1. As this diagram shows, an increase in exercise intensity at any given ozone concentration results in a decrease in group mean FEV_1.

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[33] Hackney and Linn, 1987.

[34] EPA, "Air Quality Criteria for Ozone and Other Photochemical Oxidants," August 1986.

[35] Gardner et al., 1972.

[36] Gardner and Graham, 1977.

[37] More commonly, FEV1, or the volume of air which can be expired in one second, will be measured.

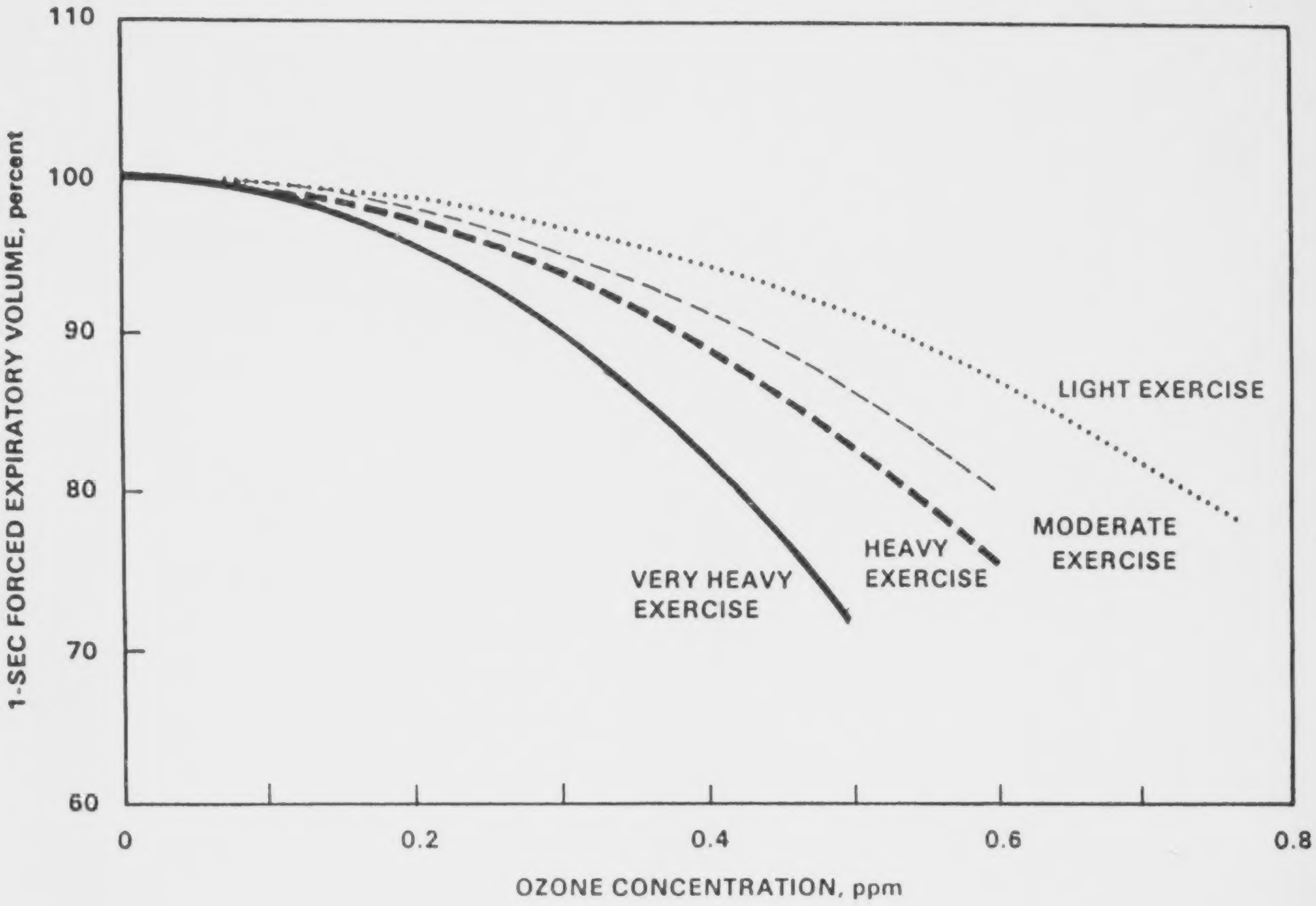

Figure 2 - 1 . Percent decreases in lung function during 2-hr ozone exposures with different levels of exercise.

Source: Air Quality Criteria for Ozone and Other Photochemical Oxidants, Vol. I of V, U.S. Environmental Protection Agency, Environmental Criteria and Assessment Office, August 1988, p. 1-158.

Prior to 1980, there was very little information on lung function changes from controlled exposures to ozone concentrations below 0.30 ppm. This was mainly because under the conditions of rest or mild exercise employed in most of these studies, there was little, if any effect from 1-2 hour exposures to ozone levels less than 0.30 ppm. However, a number of studies, using higher exercise levels, have since shown clear responses to ozone levels between 0.16-0.24 ppm.[38] [39] [40] [41] Average decreases in group mean FEV_1 ranged from 6-22%.

At ozone concentrations approaching the current ambient air quality standard for ozone, some investigators have seen small (4-6%) but statistically significant group mean decreases in FVC and FEV_1 under conditions of heavy exercise,[42] [43] while others have not.[44] [45] [46] Because of the variability in observed changes in lung function among different studies, it is difficult to draw any definite conclusions about changes in lung function in the range of 0.08 to 0.16 ppm ozone for one- or two-hour exposure periods. The most substantial responses in this range of ozone concentration occur under conditions of heavy exercise and durations of exposure longer than one hour. For example, Folinsbee and coworkers recently observed 13% group mean decreases in FEV_1 in subjects performing heavy exercise for 6.6 hours at the level of the standard, 0.12 ppm.[47]

The current controversy surrounding impairment of lung function from ozone exposure involves the definition of an "adverse" decrement in lung function. Group mean decreases in either FEV_1 or FVC of greater than 10 percent are clearly significant enough to be considered adverse, especially in light of the fact that some individuals within these groups experience decrements in lung function greater than the average. Temporary and infrequently occurring changes of less than 10 percent, in and of themselves, probably do not represent an adverse health effect for a healthy young adult. However, some health professionals would consider such changes to be adverse if they restrict activity or limit performance[48]. Short-term reversible decrements in lung function could have adverse effects in individuals with already reduced lung capacity. However, there is no universal agreement among scientists as to the implications of such "small" changes. There is also little convincing evidence available at this time to indicate whether there are long-term consequences from short-term lung function changes.

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[38] McDonnell et al., 1983.
[39] Folinsbee et al., 1984.
[40] Avol et al., 1984.
[41] Gong et al., 1986.
[42] McDonnell, 1983.
[43] Gong, 1986.
[44] Schelegle and Adams, 1986.
[45] Kulle et al., 1985.
[46] Linn et al., 1986.
[47] Folinsbee et al., 1988.
[48] Ferris et al., 1985.

Symptom Responses

Symptoms experienced by people exposed to ozone are also important markers of ozone's effects. The major symptoms -- cough and pain when breathing deeply -- typically are observed at about the same ozone exposure levels as are changes in lung function indices; heavy exercise for one hour at 0.18 ppm will cause such symptoms in *groups* of healthy young adults.[49] [50] [51] Folinsbee and coworkers' recent study (1988) demonstrated a relationship at 0.12 ppm between discomfort on deep breathing and changes in lung function (FVC) using *individual* data. However, most studies have not shown an association between symptoms and lung function changes at this ozone concentration on an individual level. Pronounced symptoms such as repeated coughing or pain when taking a deep breath will almost always be associated with substantial (greater than 10%) lung function changes.

Adults perceive symptoms of ozone exposure at low concentrations (0.12 ppm)[52] but children apparently do not.[53] [54] [55] While children are certainly capable of sensing breathing discomfort, their lack of response from these low level exposures could be the result of a higher "threshold" of perception for symptoms. It has been suggested that the weak symptom responses of children may put them at greater risk from ozone exposure because they may not make efforts to avoid being exposed if they are unable to perceive the effects. Further research is needed on the sensitivity of children to the symptoms of ozone exposure.

Potentially Susceptible Members of the Population

Implicit in the Clean Air Act's directive that EPA set air quality standards with an "adequate margin of safety" is the desire to protect the most sensitive groups in the population. Many factors may affect susceptibility to ozone exposure, including age, sex, smoking status, nutritional status, environmental stresses, and exercise level during exposure. These six factors help EPA identify groups likely to be at increased risk to ozone. At present, scientists postulate that about 5 to 20 percent of the healthy population may represent a subgroup of "responders"[56] who may be significantly more responsive than the general population to the same dose of ozone. Also considered "at-risk" are asthmatics, people with pre-existing lung disease, children, the elderly, and individuals who exercise heavily or work outdoors. Within each of these groups some individuals have demonstrated greater-than-average sensitivity to a specified dose of ozone, although no particular group has proven to be more sensitive than the others.

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[49] McDonnell et al., 1983.

[50] Avol et al., 1984.

[51] Kulle et al., 1985.

[52] McDonnell et al., 1983.

[53] McDonnell et al., 1985.

[54] Avol et al., 1985.

[55] Avol et al., 1987.

The strongest evidence for increased responsiveness exists for groups who exercise intensively outdoors because the dose of ozone they receive is much higher than average due to their increased breathing rate. Because individuals with preexisting lung disease already have compromised respiratory systems, there is concern that lung function changes and other respiratory effects may be more serious for these people than for the normal, healthy population.

Asthmatics

Results of studies on asthmatics are mixed. A number of epidemiological studies of asthmatics have suggested that ozone exposure may be associated with increased asthma attacks, hospital admissions for asthma, decrements in lung function, and symptoms.[57] [58] [59] [60] Asthmatics have also participated in studies in which lung function and symptoms were assessed before and after breathing ozone in a controlled laboratory environment. These studies have consistently shown that the lung function and symptom responses of asthmatics to a specific level of ozone do not differ from the responses of healthy non-asthmatics.[61] [62] [63]

Because of what we know about the significant difference in response to sulfur dioxide between asthmatics and non-asthmatics, the failure of asthmatics to exhibit increased sensitivity to ozone in chamber studies is somewhat surprising. However, these have been group analyses; there may be a subpopulation of asthmatics more sensitive than a subgroup of "normals" to ozone inhalation. For example, moderate to severe asthmatics have not been studied in these controlled environments. In addition, chamber studies of asthmatics have not yet been conducted at the higher exercise levels that have yielded the most significant responses in non-asthmatics. The discrepancy between results in epidemiologic and chamber studies may also be due to interaction between ozone and other environmental factors (i.e., other pollutants, high temperatures and humidity) in the field. In other words, there may be factors operating in the ambient environment that have not been replicated in clinical studies.

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[56] p. VI-13, "Review of the National Ambient Air Quality Standards for Ozone," OAQPS Draft Staff Paper, November 1987.

[57] Whittemore and Korn, 1980.

[58] Bates and Sitzo, 1987.

[59] Holguin et al., 1985

[60] Gong et al., 1987.

[61] Koenig et al., 1987.

[62] Linn et al., 1978.

[63] Linn et al., 1980.

Chronic obstructive pulmonary disease (COPD) patients

Patients with chronic obstructive pulmonary disease (COPD) (chronic bronchitis, emphysema), many of whom are former smokers, are also of concern as an "at-risk" subgroup because they already have poor lung function and, compared to healthy individuals, relatively small decrements in lung function could be adverse for them. Several different laboratory studies have been conducted on COPD patients exposed to ozone[64] [65] [66] [67] [68] but none have found them to experience significant reductions in lung function measures (FVC, FEV_1) even at concentrations as high as 0.30 ppm for 1-2 hours. It will be necessary to study these individuals over longer periods of exposure and at higher exercise levels in order to adequately evaluate the risk from ozone exposure faced by COPD patients. Out of concern for their health, studies of patients with COPD, like those asthma, have not been performed under such conditions to date.

Children

Children are another *potentially* susceptible subgroup of concern. Since the lung continues to develop until adulthood, the critical question regarding children exposed to ozone is whether repeated exposure will influence lung maturation. Relatively low concentrations of ozone (at or around the standard) do appear to have an adverse impact on the lung function of active children.[69] [70] On the basis of both controlled exposure studies and field studies of ambient pollutant exposure, however, children do not appear to have lung function effects that are much different than those experienced by adults.

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[64] Kulle et al., 1984.
[65] Linn et al., 1982.
[66] Linn et al., 1983.
[67] Solic et al., 1982.
[68] Kehrl et al., 1985.
[69] McDonnell et al., 1985.
[70] Lippmann et al., 1983.

The elderly

Concern has also been expressed for elderly members of the population. A subgroup of healthy, older adults may be at risk because they may participate in outdoor activities where they might be exposed to ozone. There is not yet a consensus, however, as to whether or not this group is at higher or lower risk for pulmonary function and other ozone-related effects than younger adults. While lung function effects have been observed in this subpopulation, several studies suggest that healthy older adults may less susceptible to the acute effects of ozone than healthy young adults.[71] [72] The extent to which pulmonary function changes reflect other events occurring in the lung of ozone-exposed older adults is unknown; further research is necessary to fully evaluate this group.

Athletes

Both epidemiologic and chamber studies have indicated that athletes may be at substantial risk of experiencing decreases in work performance and decrements in lung function when exercising for approximately one hour at ozone concentrations as low as 0.20 ppm.[73] [74] [75] Outdoor workers exposed to ozone for prolonged periods may also be at increased risk. New research shows that volunteers performing the equivalent of a day of very heavy manual labor while exposed to 0.12 ppm ozone experience significant loss in lung function (13% group mean decrease in FEV_1) and pronounced symptoms (e.g. cough, pain when inhaling deeply).[76] This research suggests that extended periods of heavy exercise may be undesirable from the point of view of respiratory health and physical performance, not only during periods of high ozone concentrations (greater than 0.20 ppm), but also at levels found in many nonattainment cities (0.12-0.18 ppm).

The acute effects of ozone exposure (e.g. decreases in lung function and symptomatic responses) are summarized in Figure 2-2, which illustrates the ozone level at which these effects begin. The figure is divided into two sections: the upper section describes effects that occur with 1-3 hour exposures, the lower section for 4-8 hour exposures. The tail of the arrow indicates the concentration at which an effect may begin. At the lowest concentrations at which effects are seen, the exposures are typically accompanied by very

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[71] Drechsler-Parks, 1987.

[72] Reisenauer et al., 1988.

[73] Folinsbee et al., 1984.

[74] Gong et al., 1986.

[75] Schlegle and Adams, 1986.

[76] Folinsbee et al., 1988.

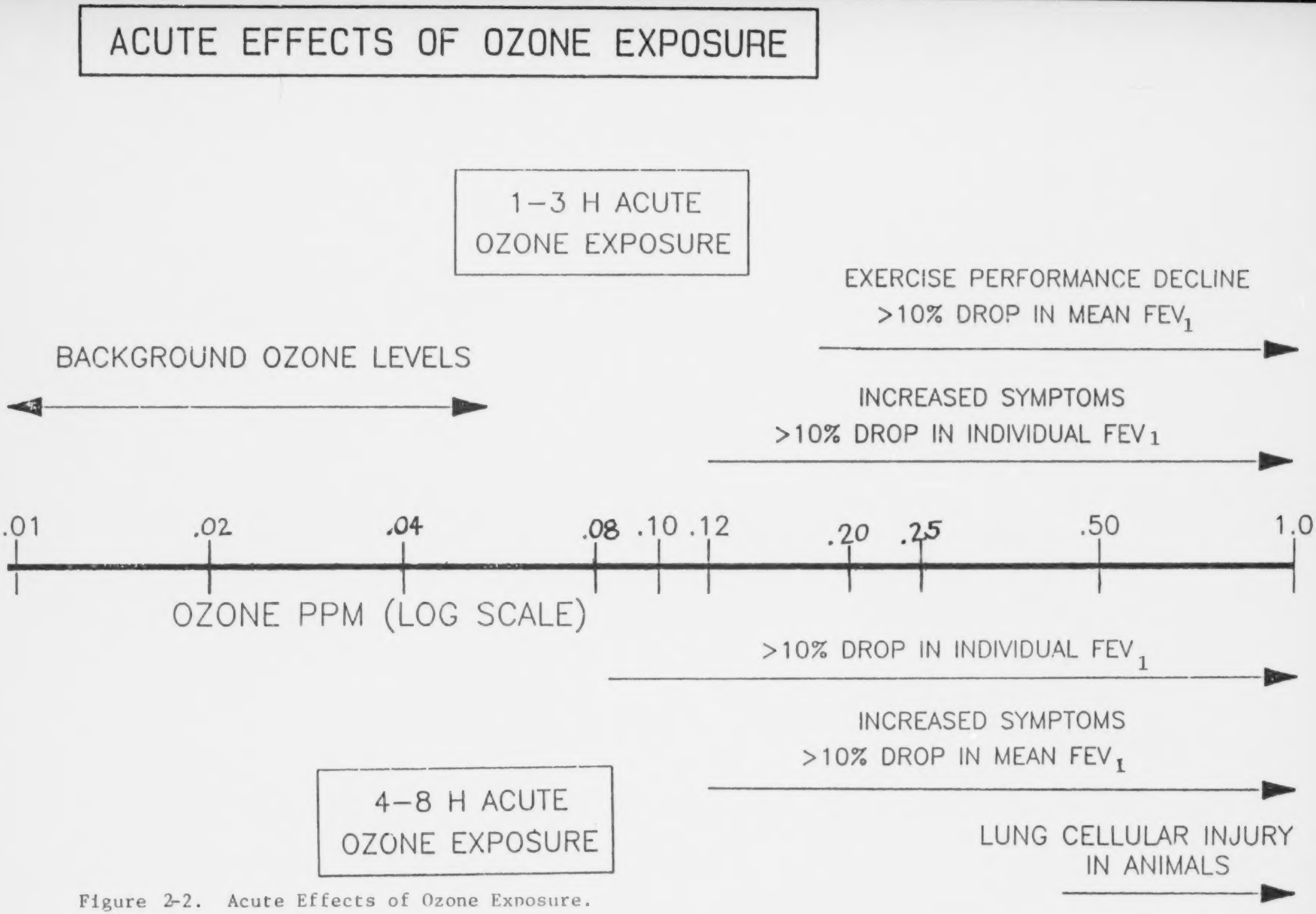
ACUTE EFFECTS OF OZONE EXPOSURE
1-3 H ACUTE OZONE EXPOSURE
EXERCISE PERFORMANCE DECLINE
>10% DROP IN MEAN FEV1
BACKGROUND OZONE LEVELS
INCREASED SYMPTOMS
>10% DROP IN INDIVIDUAL FEV1
.01
.02
.04
.08
.10
.12
.20
.25
.50
1.0
OZONE PPM (LOG SCALE)
>10% DROP IN INDIVIDUAL FEV1
INCREASED SYMPTOMS
>10% DROP IN MEAN FEV1
4-8 H ACUTE OZONE EXPOSURE
LUNG CELLULAR INJURY IN ANIMALS

Figure 2-2. Acute Effects of Ozone Exposure.

Note: All effects above ozone scale line are associated with 1-3 h acute (short-term) exposure; all effects below line are associated with 4-8 h acute exposure. Also, FEV_1 is one measure of pulmonary function that may indicate airway obstruction in the lungs.

Source: Draft Report for OTA by Lawrence J. Folinsbee, "A Summary of the Health Effects of Ozone," Jan. 1988.

heavy exercise. With moderate or mild exercise, effects would begin at higher ozone concentrations. Also, more adverse responses, such as cell damage shown in laboratory animal studies, tend to occur at the higher concentrations.

2.2 Exposure to Ozone

Areas Failing to Meet the Standard

An area is designated "nonattainment" for ozone if concentrations exceeding 0.12 ppm (1-hour average) are measured on more than three days over a three year period at any monitoring site in the area (i.e. the area is expected to exceed the standard more than once per year, averaged over three years).

Figure 2-3 shows the metropolitan statistical areas (MSAs) and grouped or "consolidated" metropolitan statistical areas (CMSAs) that were classified as ozone nonattainment areas based on 1983-1985 monitoring data. The areas are listed in Table 2-2. As indicated in the table, several non-MSA areas were also designated nonattainment but are not shown on the map.[77]

EPA updates the list of nonattainment areas every year as data for a new season become available. Based on the 1983-1985 data, 76 urban areas (encompassing 94 individual MSAs plus the ten non-MSA areas) were designated nonattainment. In contrast, 62 areas were designated nonattainment based on the 1984-1986 period (16 areas were dropped in 1986 and 2 areas were added). The difference is primarily attributable to differences in weather between the two periods. The nonattainment list from the 1983-1985 period has been used here for consistency with other parts of this assessment, and because the list for the most recent three-year time period -- 1985-1987, is not yet available. The list of nonattainment areas for 1985-1987 is expected to match the 1983-1985 list more closely than it matches the 1984-1986 list, because the relatively hot summers of 1983 and 1987 both saw higher numbers of violations of the ozone standard than the intervening summers did.

The shading in Figure 2-3 indicates the 1983-1985 "design value" for each area. The design value is a measure of the highest daily maximum 1-hour average ozone concentrations in the area and is the fourth highest of all of the daily peak 1-hour average ozone concentrations observed within the area over the most recent three year period. Areas with design values of 0.13 ppm or higher are violating the ozone standard. On average, the higher the design value, the greater the level of emissions control required to prevent violations of

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[77] The non-MSA areas are Dover, DE; Seaford, DE; Iberville Parish, LA; Pointe Coupee Parish, LA; St. James Parish, LA; Acadia National Park, ME; Gardiner County, ME; Hancock County, ME; York County, ME; and Northampton County, VA.

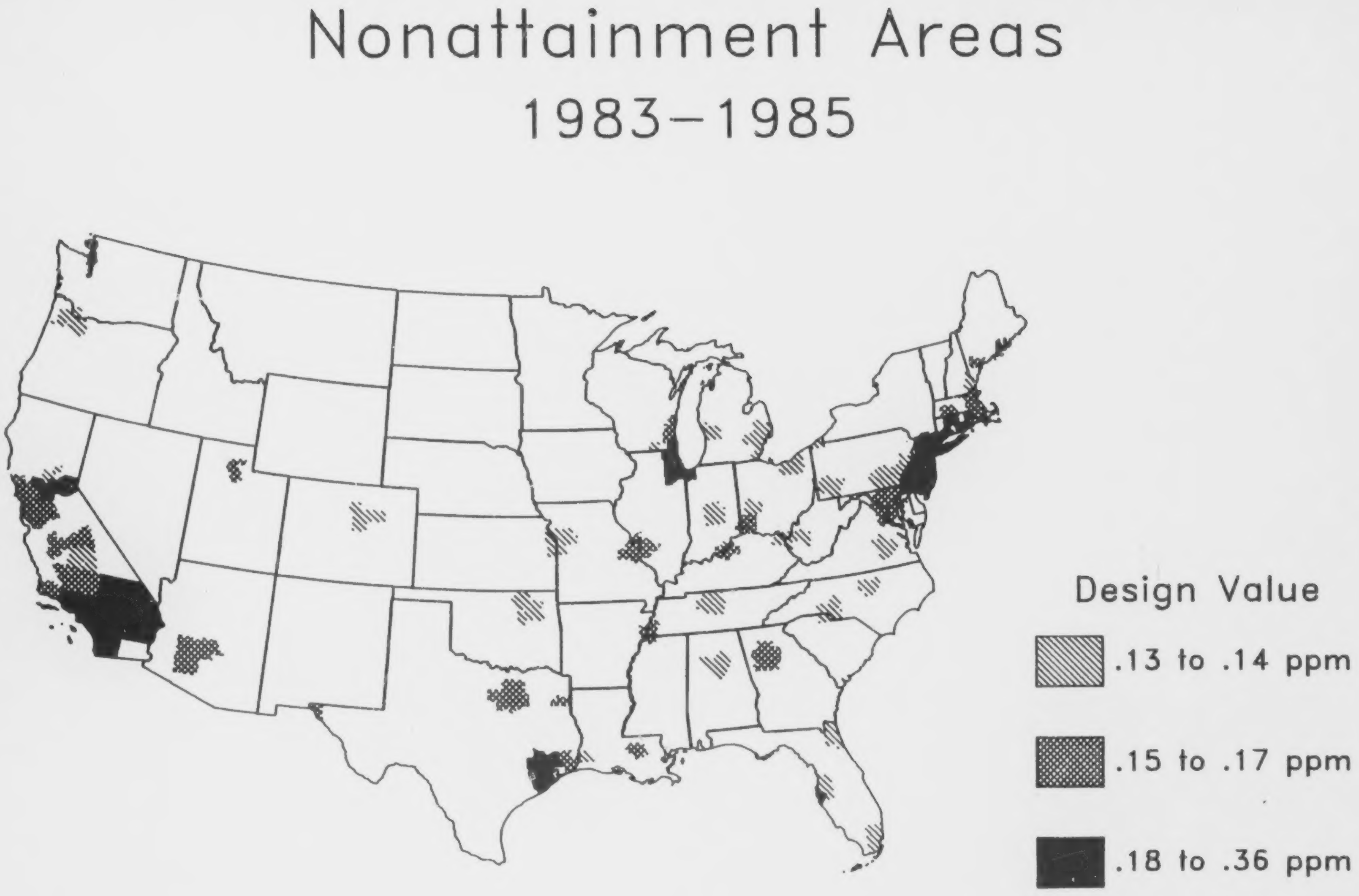

Figure 2-3. Areas classified as nonattainment for ozone based on 1983-1985 data. The areas shown are listed in Table 2-2. The shading indicates the fourth highest daily maximum 1-hour ozone concentration or "design value" for each area.

Table 2-2. Areas classified as nonattainment for ozone based on 1983-1985 data.
* -- non-MSA area. ** -- multi-MSA consolidated area.

Area Name	Design Value (ppm)
0.13 to 0.14 ppm	
Acadia National Park, ME*	0.13
Allentown-Bethlehem, PA	0.14
Birmingham, AL**	0.13
Charleston, WV	0.13
Charlotte-Gastonia-Rock Hill, NC-SC	0.13
Cleveland, OH**	0.14
Dayton-Springfield, OH	0.13
Denver-Boulder, CO**	0.13
Detroit, MI**	0.13
Dover, DE*	0.14
Erie, PA	0.13
Gardiner, ME*	0.14
Grand Rapids, MI	0.13
Hancock Co., ME*	0.13
Harrisburg-Lebanon-Carlisle, PA	0.13
Huntington-Ashland, WV-KY-OH	0.14
Iberville Parish, LA*	0.13
Indianapolis, IN	0.13
Jacksonville, FL	0.14
Janesville-Beloit, WI	0.13
Kansas City, MO-KS	0.14
Lake Charles, LA	0.14
Lancaster, PA	0.13
Miami-Hialeah, FL**	0.13
Muskegon, MI	0.14
Nashville, TN	0.14
Northampton Co, VA*	0.14
Pittsburgh, PA**	0.13
Pointe Coupee Parish, LA*	0.13
Portland, OR-WA**	0.13
Portsmouth-Dover-Rochester, NH-ME	0.13
Reading, PA	0.13
Richmond-Petersburg, VA	0.13
St James Parish, LA*	0.13
Tampa-St Petersburg-Clearwater, FL**	0.13
Tulsa, OK	0.13
Visalia-Tulare-Porterville, CA	0.13
York, PA	0.13
Yuba City, CA	0.13

Table 2-2. (Cont.) Areas classified as nonattainment for ozone based on 1983-1985 data.
* -- non-MSA area. ** -- multi-MSA consolidated area.

Area Name	Design Value (ppm)
0.15 to 0.17 ppm	
Atlanta, GA	0.16
Bakersfield, CA	0.16
Baltimore, MD	0.17
Baton Rouge, LA	0.16
Beaumont-Port Arthur, TX	0.16
Boston, MA**	0.16
Cincinnati, OH-KY-IN**	0.17
Dallas-Ft Worth, TX**	0.16
El Paso, TX	0.16
Fresno, CA	0.17
Longview-Marshall, TX	0.15
Louisville, KY-IN	0.15
Memphis, TN-AR-MS	0.15
Milwaukee, WI**	0.17
Modesto, CA	0.15
New Bedford, MA	0.16
Phoenix, AZ	0.16
Portland, ME	0.16
Salt Lake City-Ogden, UT	0.15
Santa Barbara-Santa Maria-Lompoc, CA	0.16
Seaford, DE*	0.15
St Louis, MO-IL**	0.16
Stockton, CA	0.15
Washington, DC-MD-VA	0.16
Worcester, MA	0.15
York Co, ME*	0.15
San Francisco, CA**	0.17
0.18 to 0.26 ppm	
Atlantic City, NJ	0.19
Chicago, IL**	0.20
Greater Connecticut**	0.23
Houston, TX**	0.25
New York, NY**	0.22
Philadelphia, PA-NJ**	0.18
Providence, RI**	0.18
Sacramento, CA	0.18
San Diego, CA	0.21
0.27 ppm or higher	
Los Angeles-Long Beach, CA**	0.36

the standard. For the 1983-1985 period, 39 areas had design values of 0.13 or 0.14 ppm, 27 areas had design values of 0.15 to 0.17 ppm, and 10 areas had design values of 0.18 ppm or more. The highest design value for any area was 0.36 ppm, for Los Angeles, CA.

Frequency and Magnitude of Violations

Figures 2-4 through 2-6 show the areas throughout the contiguous United States where ozone concentrations exceeded 0.12 ppm, 0.14 ppm and 0.18 ppm, respectively, at least one hour per year, averaged over the years from 1983 to 1985. By averaging data from all of the monitors in each area, the maps indicate the number of hours each concentration level was typically exceeded.[78] The data shown were obtained from EPA.[79] The all-monitor average statistics are assumed to be more representative of air quality throughout each area than data for the peak monitor (the monitor where the highest concentrations were recorded) would be. Note that more areas would be expected to exceed the specified concentrations if data for the peak monitor in each area were used.

Of the 317 (urban and nonurban) areas for which we have ozone data, Figure 2-4 shows the 130 areas where a concentration of 0.12 ppm was exceeded at least one hour per year, on average, between 1983 and 1985.[80] Sixty of those areas had concentrations equal to or greater than 0.12 ppm six or more hours per year. The Dallas, Houston and Atlanta areas and parts of California, New York, New Jersey and Connecticut all recorded concentrations greater than or equal to 0.12 ppm more than 20 hours per year. The maximum number of hours that monitored ozone concentrations exceeded 0.12 ppm in any one area was 275 hours per year.

Figure 2-5 shows the 60 areas where the all-monitor average statistics indicate that ozone concentrations reached 0.14 ppm at least one hour per year between 1983 and 1985. Twenty-four of these areas recorded ozone concentrations of at least 0.14 ppm six or more hours per year. Seven areas, namely the Houston area and parts of Connecticut and southern California, recorded concentrations of 0.14 ppm or higher more than 20 hours per year.

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[78] The number of monitors in each area ranges from one to 18 (in Los Angeles). The average number of monitors in each area is three.

[79] SAROAD, 1987.

[80] If data for the peak monitor in each area had been used instead of the all monitor average statistics, 146 areas would be indicated as having ozone concentrations greater than or equal to 0.12 ppm at least one hour per year.

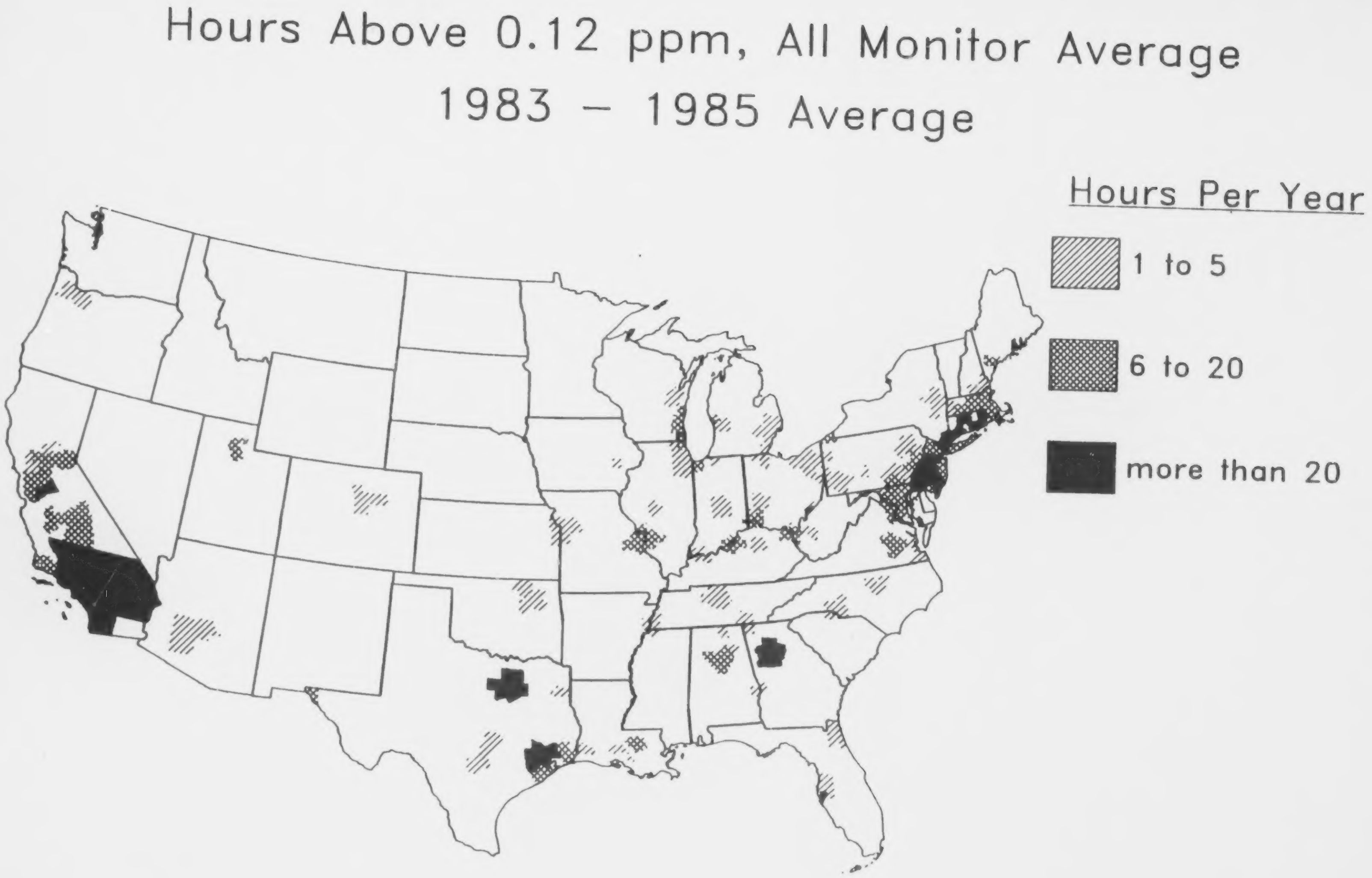
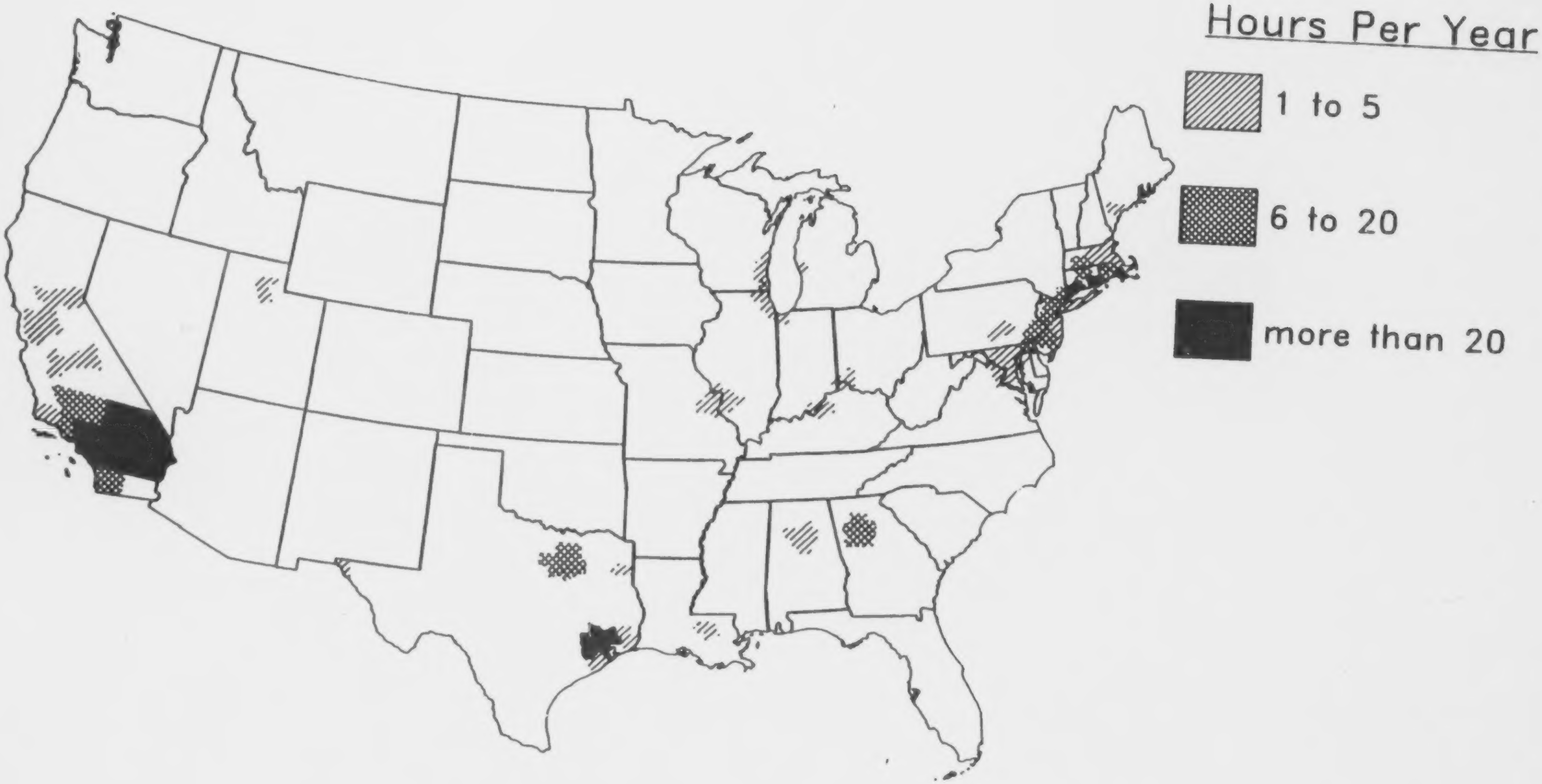


Figure 2-4. Areas where ozone concentrations exceeded 0.12 ppm at least one hour per year, on average from 1983 through 1985. Data from all of the monitors in each area were averaged in constructing the map. The shading indicates the number of hours that a concentration of 0.12 ppm was exceeded. One hundred thirty million people reside in the areas shown.



Hours Above 0.14 ppm, All Monitor Average
1983 – 1985 Average

Figure 2-5. Areas where ozone concentrations exceeded 0.14 ppm at least one hour per year, on average from 1983 through 1985. Data from all of the monitors in each area were averaged in constructing the map. The shading indicates the number of hours that a concentration of 0.14 ppm was exceeded. Eighty six million people reside in the areas shown.

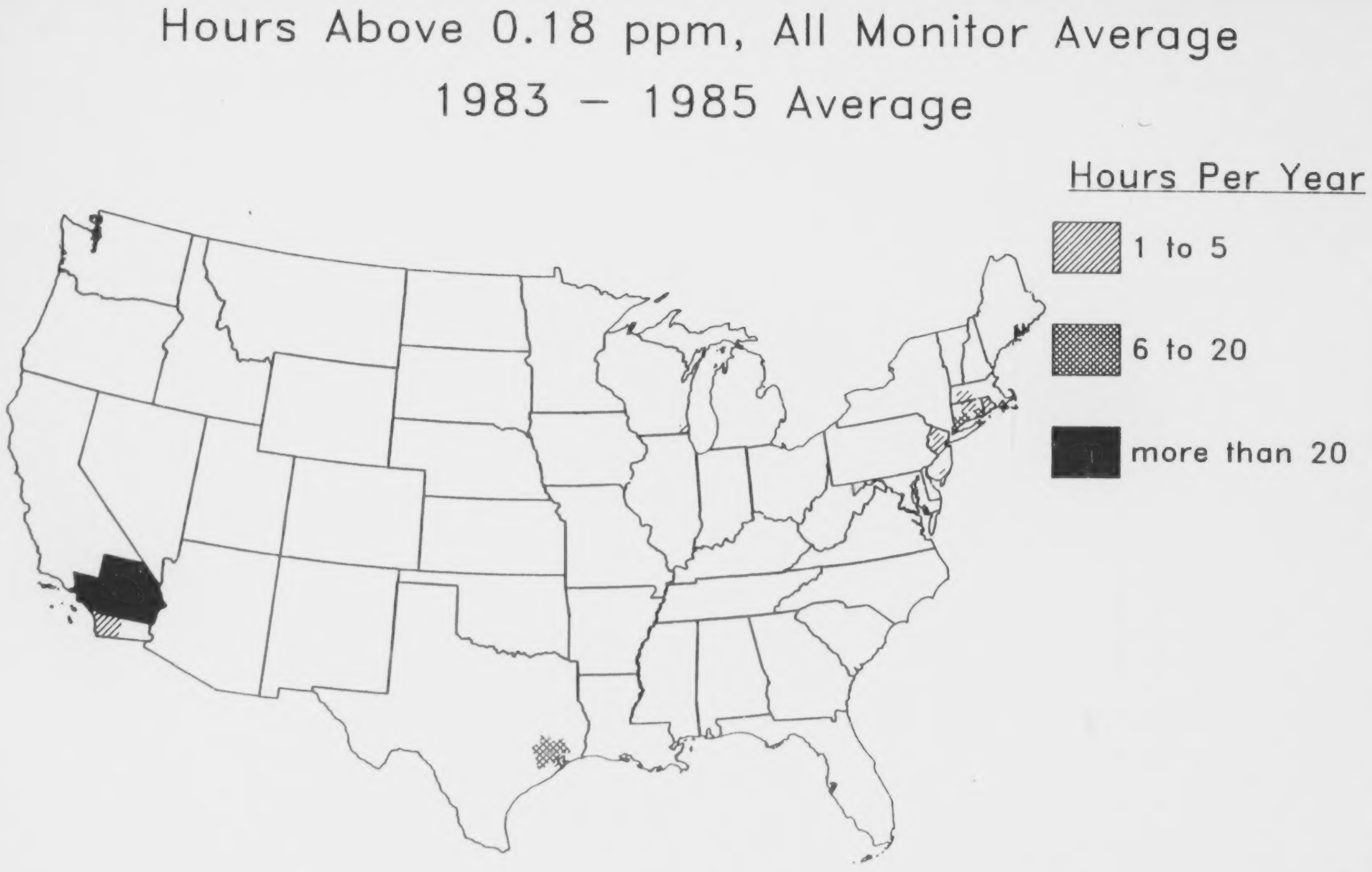


Figure 2-6. Areas where ozone concentrations exceeded 0.18 ppm at least one hour per year, on average from 1983 through 1985. Data from all of the monitors in each area were averaged in constructing the map. The shading indicates the number of hours that a concentration of 0.18 ppm was exceeded. Twenty five million people reside in the areas shown.

Figure 2-6 shows the eighteen areas where concentrations were as high as 0.18 ppm for one or more hours per year between 1983 and 1985. The all-monitor average statistics indicate that concentrations exceeded 0.18 ppm six or more hours per year in Houston and in two areas in Connecticut. Concentrations reached 0.18 ppm more than 20 hours per year in three areas in southern California.

Factors Influencing Exposure to Ozone

Just because an individual lives in an area where ozone concentrations of 0.14 ppm (for example) have been measured does not mean that he or she has been exposed to ozone concentrations at that level, or that if exposed, he or she would experience adverse health effects. This section discusses some of the factors that determine what a specified measured ozone concentration means for human health. The factors that need to be kept in mind include:

1) How outdoor ozone concentrations vary over time and location within a city;

2) Where people are and for how long -- especially how much time they spend outdoors versus indoors, where concentrations are lower;

3) People's activity levels -- which determine their breathing rate and the depth of the breaths they take, and thus the amount of ozone they inhale over a given period of time; and

4) Person-to-person variability in how sensitive people are to ozone.

At urban locations, ozone concentrations usually peak during the early to mid-afternoon, after building up throughout the morning. At suburban and rural locations, the peak concentrations usually occur later in the afternoon or early evening. Figure 2-7 shows a profile of ozone concentrations as they change over the day at a single monitoring site.[81] The profile is typical of a suburban area downwind of the center of a major city. Especially at suburban and rural locations, ozone concentrations often stay within 10 to 20 percent of the peak one-hour average concentration for several hours.

The first step in relating measured ozone concentrations to potential health effects is to estimate from the monitor readings the pollutant concentrations to which people have actually been exposed. Figure 2-8 shows a contour map of how peak ozone concentrations on a given day vary across the New York City metropolitan area.[82] The diagram shows

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[81] Adapted from U.S. EPA, 1986.

[82] Adapted from Rao, 1987.

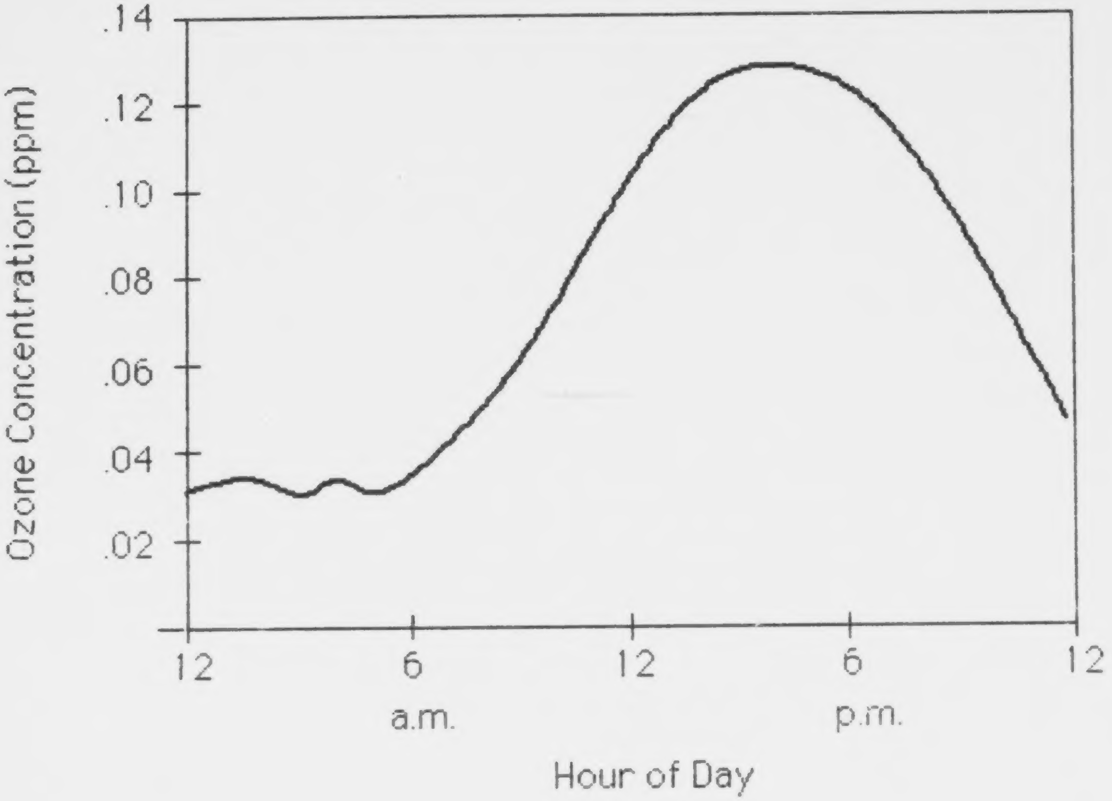

Figure 2-7. Profile of ozone concentrations as they change over the day at a single monitoring site [adapted from U.S. EPA, 1986]. The profile is typical of a suburban area downwind of a strong source area or city center.

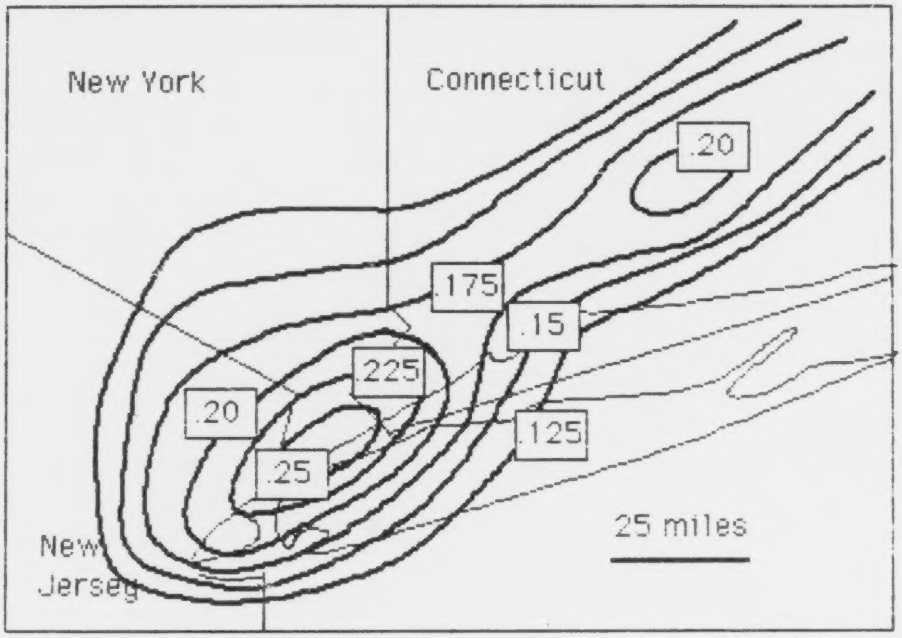

Figure 2-8. Contour map of the variation in daily peak ozone concentrations (ppm) predicted for the New York City area using a model with meteorological conditions and emissions of July 16, 1980 [adapted from Rao, 1987]. As shown, ozone concentrations typically vary smoothly over a large area and do not show localized peaks.

ozone concentrations predicted using a model, with meteorological conditions and emissions of July 16, 1980 as inputs. As shown in the example, at any one time, outdoor ozone concentrations can vary by a factor of two or more across an urban area. However, as shown in Figure 2-8, ozone concentrations tend to vary smoothly over large areas, and not to show sharp, localized peaks.[83]

People who are outdoors during the afternoon when ozone concentrations reach their peak are apt to be exposed to higher ozone concentrations than people who are indoors. In air conditioned buildings, indoor ozone concentrations are typically about 30 percent of those measured outdoors at the same location.[84] Ozone concentrations inside buildings with open windows instead of air conditioning are estimated to be about 60 percent of outdoor concentrations.[85] Most people spend 80 to 90 percent of their time indoors. Note, however, that some people work or recreate outdoors most of the day. About 5 percent of adult men work mostly outdoors. An additional 10 percent work outside part of the time. The proportion of women who work outside is thought to be somewhat lower.[86]

Two factors determine the total amount of ozone an individual inhales over a given period of time: (1) the ozone concentrations to which the person is exposed; and (2) the depth and rate at which the individual is breathing. The depth and rate at which someone breathes is determined by the level of exercise he or she is performing. Since the amount of air and thus the amount of ozone inhaled increases with increasing physical exertion, people who are exercising or doing vigorous labor outdoors are more likely to experience health effects due to elevated ozone concentrations than people who are sitting, standing or walking at a leisurely pace. As examples, recreational jogging, swimming and bicycling can constitute heavy exercise. Those who compete in these sports are likely to be attaining very heavy exercise levels.[87]

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[83] One exception to this general rule is that in the plumes of large NO_x sources, up to about a mile downwind of the source, ozone concentrations can be much lower than in the surrounding air. This is because extremely high concentrations of NO_x without comparably high VOC concentrations destroy ozone faster than it is produced. However, as the NO_x plume disperses, VOC and NO_x levels come into balance and net ozone production results.

[84] Paul et al., 1986.

[85] Ibid.

[86] Pope, 1986.

[87] A 1984 Gallup survey indicated that about 18 percent of adult Americans jog at least once per week [Gallup, 1984]. Four out of every 1000 adults (0.4 percent) run more than six miles at least once per week [Gallup, 1983].

As discussed in the section on health effects, clinical and epidemiological studies have shown that different people respond differently to ozone even when they are exposed to the same concentrations over the same time period and are breathing at the same rate. From five to twenty percent of the population of healthy adults are thought to be very sensitive to ozone. The reasons for their heightened sensitivity have not been established.

Population Exposure Estimates

Based on 1984 census estimates[88] and the data presented in Figures 2-4 to 2-6, approximately 130 million people live in areas where ozone concentrations are expected to equal or exceed 0.12 ppm at least one hour per year. Eighty-six million people live in areas where concentrations reach at least 0.14 ppm at least one hour per year; 25 million where concentrations reach at least 0.18 ppm; and 10 million live in the Los Angeles and Anaheim, CA MSAs where ozone concentrations reach or exceed 0.25 ppm.

Of the 130 million people who live in areas where ozone concentrations reach or exceed 0.12 ppm, 43 percent (56 million) live in areas where concentrations reach 0.12 ppm six or more hours per year; 34 percent (44 million) in areas where concentrations reach 0.12 ppm at least 20 hours per year, and almost ten percent (12 million) in areas (Los Angeles, Riverside and Anaheim, CA) where ozone concentrations reach 0.12 ppm more than 100 hours each year. As with the maps presented above, it is important to note that the preceding estimates are based on the average of all of the monitors in each area, not the "peak" monitor.

The population statistics presented above might be considered the number of people "potentially" exposed to ozone -- people who, if they were outside at the "right" time and location, would be exposed to ozone concentrations above the level at which the current ozone standard is set. Table 2-3 presents estimates of actual exposures: the number of people who do happen to be in the right place at the right time to be exposed to concentrations above 0.12 ppm for at least an hour; and for each person who is exposed, the average number of times each year that exposures occur. The numbers given in Table 2-3 were calculated by combining EPA's exposure estimates[89] with the number of people we have estimated who live in areas where ozone concentrations are expected to exceed 0.12 ppm more than one hour per year.

The numbers given in Table 2-3 are broken down by the exercise levels at which the exposures were estimated to have occurred. Recall that people exercising at higher levels are expected to be more susceptible to health impacts. Nationwide, 34 million people are

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[88] Department of Commerce, 1986.

[89] McCurdy, 1988.

Table 2-3. Estimated exposures to ozone concentrations above 0.12 ppm [adapted from McCurdy, 1988]. The estimates are based on hourly ozone data for the period 1983-1985, and take into account people's activity patterns (e.g. time commuting, time indoors at work, etc.) location throughout the day. The estimates are broken down according to people's exercise levels, as those exercising at the higher levels are most apt to be susceptible to health impacts. The total number of people residing in areas where the ozone standard was exceeded at least one hour per year, on average during 1983-1985, was approximately 130 million.

Exercise level	People Exposed	Percent of People in Areas Exceeding 0.12 ppm	Hours of Exposure Per Person Exposed
Nationwide			
sedentary	34 million	26 %	8.8 hours
low	21 million	27 %	8.6 hours
moderate	13 million	27 %	5.7 hours
heavy	80 thousand	23 %	4.1 hours
Nationwide except Los Angeles			
sedentary	24 million	20 %	3.7 hours
low	16 million	23 %	4.6 hours
moderate	10 million	23 %	3.2 hours
heavy	60 thousand	19 %	2.1 hours
Los Angeles			
sedentary	9.7 million	97 %	22 hours
low	4.6 million	77 %	24 hours
moderate	3.0 million	83 %	14 hours
heavy	20 thousand	73 %	10 hours

estimated to be exposed each year at sedentary exercise levels; 21 million at low exercise levels; 13 million at moderate exercise levels; and approximately 80 thousand during heavy exercise. In each exercise category, these numbers represent about 25 percent of the people who achieve that exercise level some time during the year. Since everyone is sedentary at some time (e.g. when they are sitting and talking), about 25 percent of the people who live in areas where ozone concentrations exceed 0.12 ppm are estimated to be exposed to concentrations at or above this level. By far the most people are exposed at sedentary or low exercise levels. Fewer people are exposed at the highest exercise level, because few people engage in heavy exercise. Of the nationwide totals, 9.7 million, 4.6 million, 3 million and 20 thousand of the people exposed at sedentary, low, moderate and high levels, respectively, are residents of the Los Angeles area.

On a nationwide basis, people who are exposed to ozone concentrations of 0.12 ppm at low exercise levels are estimated to be exposed an average of about 9 hours per year; people exposed at moderate levels an average of 5.7 hours per year; and people exposed at high exercise levels an average of 4.1 hours per year. However, the national averages mask considerable variability amongst urban areas. In particular, the national figures are skewed by the high incidence of exposures in the Los Angeles area. In Los Angeles, the average numbers of hours people are exposed at sedentary, low, moderate and high exercise levels are estimated to be 22, 24, 14 and 10 hours per year per person exposed, respectively. For the rest of the country, with the Los Angeles estimates subtracted out, the estimated numbers of hours of exposure are, respectively, 3.7, 4.6, 3.2 and 2.1 hours per year for people exposed at sedentary, low, moderate and high exercise levels.

2.3 Effects of Ozone on Crops and Forests

At concentrations that occur in rural areas throughout the southern and eastern halves of the United States, ozone reduces yields of economically important crops by from one to 20 percent, compared to yields that would be expected if ozone concentrations did not exceed natural background levels.[90] Annual agricultural benefits on the order of $2 billion per year [1985 $] would be expected to result from increased crop productivity if ozone concentrations in rural areas were reduced by 25 percent from current levels.[91] [92]

Forest damage (visible foliar injury, reduced growth rates, death of individual trees and succession of dominant species) in Southern California has been clearly linked to exposure to elevated ozone concentrations. Ozone has been shown to produce foliar injury and/or reduce growth rates in young trees of numerous species in controlled experiments. Ozone is suspected as being partially responsible (along with other pollutants and natural stresses) for forest declines observed in parts of the eastern United States and southern Canada. Over the last 20 to 25 years, in a variety of locations, significant fractions of the trees in stands of several species have exhibited foliar injury or decreased growth rates or both. In several cases, the location and timing of the declines suggest that air pollutants have contributed. The forest-related benefits of reducing ozone concentrations cannot currently be estimated.

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[90] Heck et al., 1984.

[91] Kopp et al., 1984.

[92] Kopp et al., 1984.

This section reviews the effects of ozone on crops, indicates where elevated ozone concentrations correspond to agricultural production, and briefly discusses estimates of the agricultural benefits of reducing ozone concentrations. The section then reviews what is understood about the effects of ozone on trees and forest ecosystems, shows the location of major forested areas, and then discusses five cases in which ozone has been suggested as a cause of forest decline.

Concentrations of Ozone in Rural Areas

Fewer than 100 ozone monitors are located in agricultural areas across the United States.[93] A number of States do not have any monitors. Thus for much of the country, only rough estimates of ozone concentrations in agricultural and forested areas can be made.

For rural monitors, Figure 2-9 shows daily maximum 7-hour average ozone concentrations averaged over the 1984 growing season.[94] [95] The concentrations range from 0.038 to 0.065 ppm. For comparison, the natural background value of the seasonal average daily maximum 7-hour average statistic is estimated to be between 0.025 and 0.030 ppm. The highest concentrations are seen at sites in Connecticut, New Jersey, Georgia, Texas and California. A general trend of increasing seasonal-average concentrations from north to south is expected due to the fact that sunlight intensity increases as one moves south. Note that the concentrations shown are from rural, but not necessarily remote monitoring sites, and may be affected by pollution from urban areas within a few hours upwind.

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[93] OAQPS, 1987.

[94] NAPAP, 1987.

[95] Recent studies have suggested that for many crops, cumulative exposure to ozone concentrations above thresholds of 0.08 to 0.10 ppm is a somewhat better measure of exposure than the seven-hour seasonal average ozone concentration. However, the seven-hour seasonal average concentration is more widely reported.

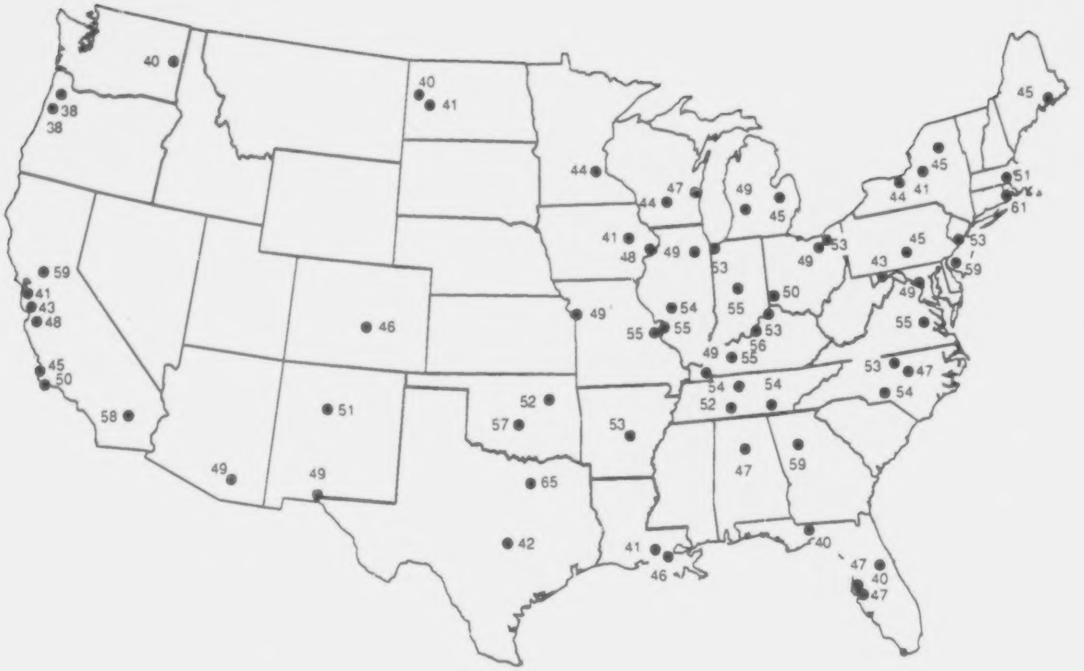

Figure 2-9. Daily maximum 7-hour average ozone concentrations (ppb) measured at rural monitoring sites and averaged over the 1984 growing season [NAPAP, 1987].

Effects of Ozone on Crops

Visible symptoms of injury due to ozone include light flecks, dark stipples and yellow spots or patches on plant leaves. Chronic exposures can induce premature "senescence" or maturation and loss of leaves. The minimum concentrations of ozone that produce acute foliar injury in susceptible plants exposed for four hours range from 0.04 ppm to 0.09 ppm, depending on the plant species.[96] Among other environmental factors, light conditions, temperature, relative humidity and soil water content affect how plants respond to ozone exposures.

For field and cash crops, the most important responses to ozone are reduced growth rates and yields. These effects may occur without the visible signs of injury usually associated with exposure to ozone. However, early senescence of leaves is usually found. Growth and yield reductions result primarily from reduced photosynthesis and transport of carbohydrates within plants. Table 2-4 displays the yield reductions predicted to occur for various crops exposed to seasonal average seven-hour mean ozone concentrations of 0.04 and 0.06 ppm.[97] The yield-reduction predictions are from the National Crop Loss Assessment Program (NCLAN), an eight-year study in which crops were grown in the field either in air filtered to assumed background ozone concentrations, ambient air, or air to which extra ozone had been added. The reductions shown in the table are relative to the yields obtained for crops exposed to assumed background ozone concentrations. The range of yield reductions indicated for each crop indicates differences among varieties.

Figure 2-10 shows state-level production of each of the four crops listed in Table 2-4. Figure 2-9 showed that seasonal average seven-hour mean concentrations of 0.04 ppm were widely exceeded in 1984 and that concentrations higher than 0.06 ppm were measured at a few locations. Note that due to year to year variability in weather, concentrations would be higher at some sites and lower at others, if data for a year other than 1984 were shown. Elevated ozone concentrations throughout the south impact cotton. The major soybean producing regions of the Mississippi and Ohio River valleys and corn producing regions throughout the eastern half of the United States and Texas are also impacted. High concentrations affect wheat production in most areas where it is grown, except in the northern plains states. In addition to the major crops listed in Table 2-4, yield reductions have been seen with a wide variety of other crops including alfalfa, clover, sorghum, barley, dry bean, root crops, tomatoes, spinach, lettuce and other produce.

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[96] Jacobson, 1977, as cited in U.S. EPA, 1987.

[97] EPA, 1987.

Table 2-4. Yield losses predicted to occur for seasonal average seven-hour mean ozone concentrations of 0.04 and 0.06 ppm [EPA, 1987]. The 0.04 ppm level is exceeded throughout the southern and eastern halves of the United States. The 0.06 ppm level is exceeded in parts of the northeast, California, Texas and Georgia. Natural background seasonal average seven-hour mean ozone concentrations are thought to be about 0.025 to 0.03 ppm.

	0.04 ppm ozone percent yield reduction	0.06 ppm ozone percent yield reduction
cotton	4.6 to 16	16 to 35
wheat	0.0 to 29	0.9 to 51
soybeans	1.7 to 15	5.3 to 24
corn	0.0 to 1.4	0.3 to 5.1

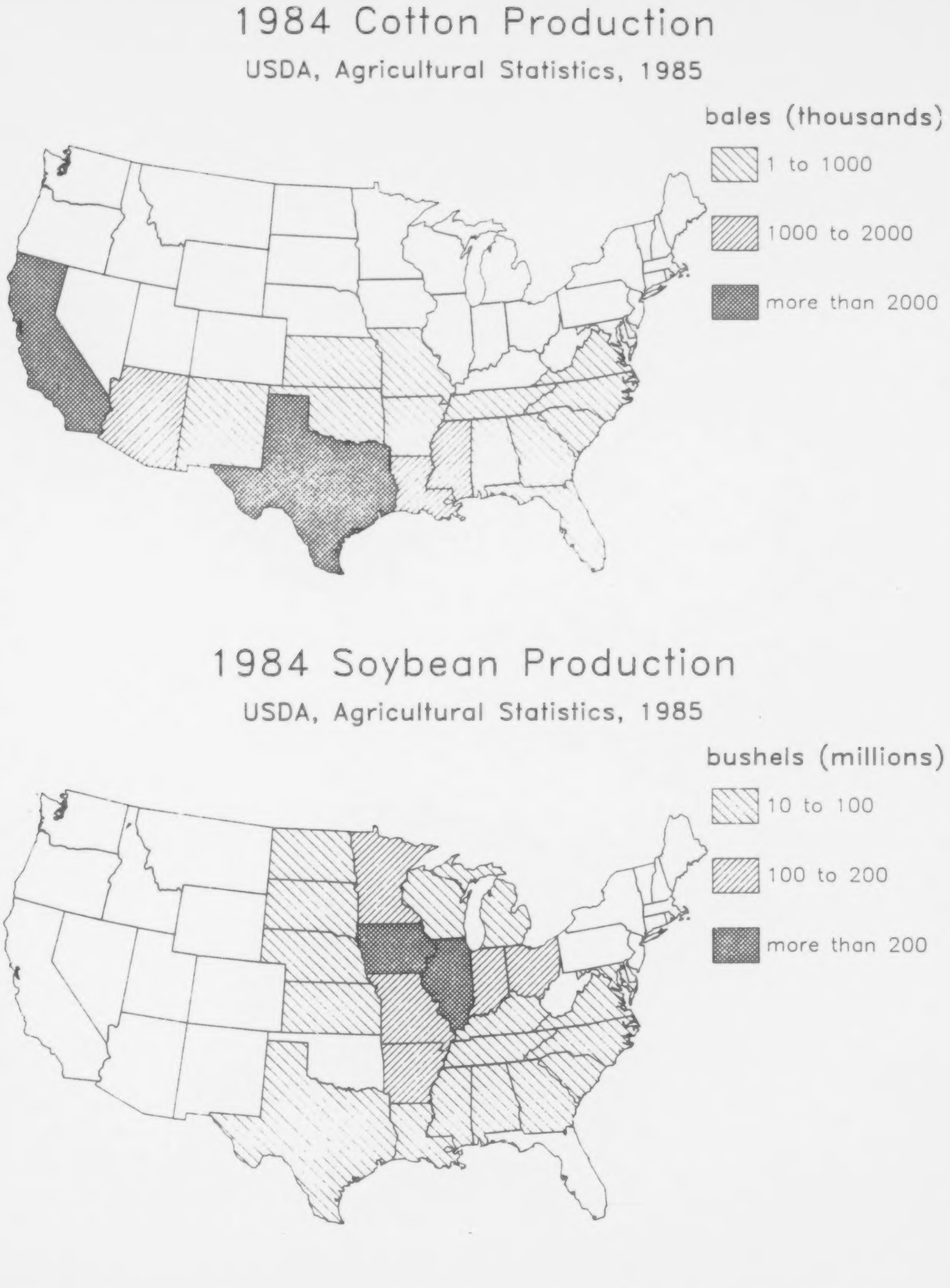
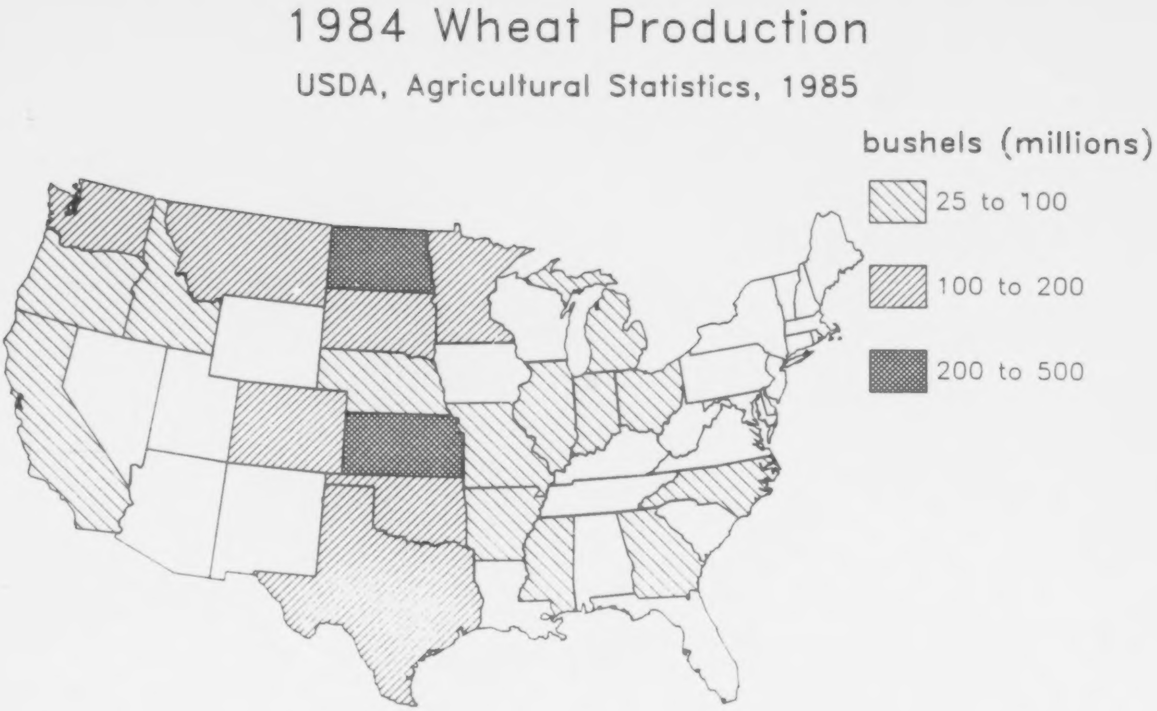


Figure 2-10. 1984 state-level (a) cotton and (b) soybean production [USDA, Agricultural Statistics, 1985].



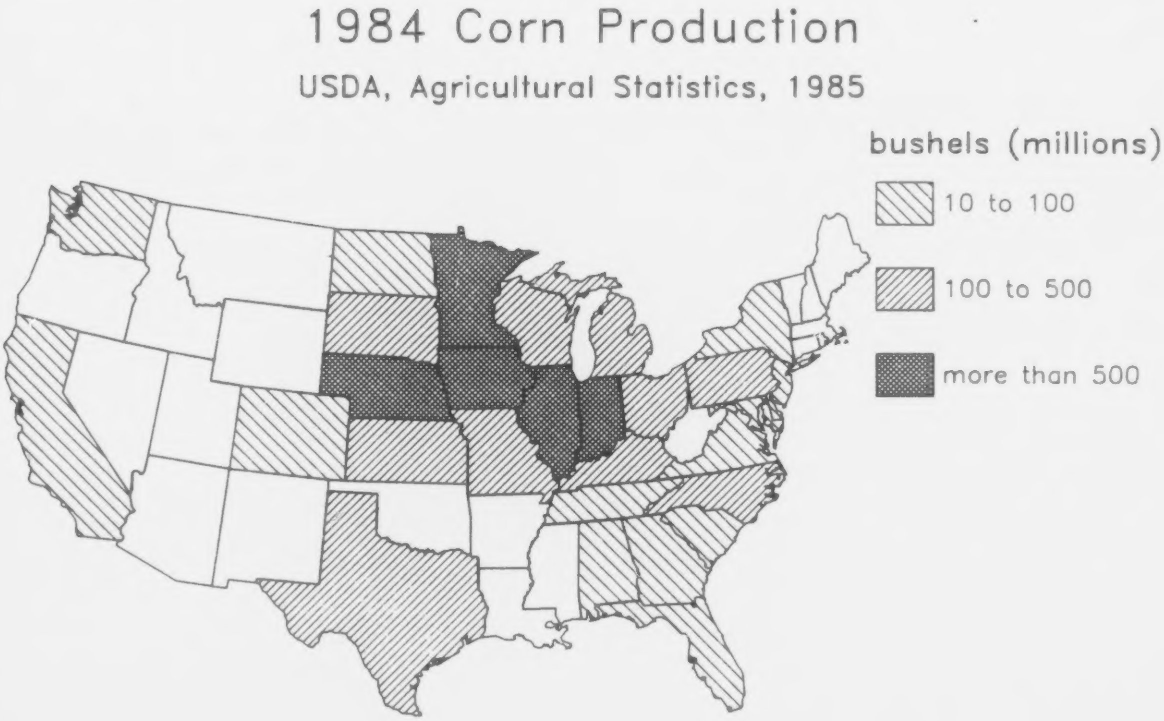


Figure 2-10. 1984 state-level (c) wheat and (d) corn production [USDA, Agricultural Statistics, 1985].

Based on NCLAN's predicted yield responses, economic models of crop supply and demand have been developed to estimate the agricultural benefits of reducing ozone concentrations.[98] [99] Reductions in ozone concentrations alter the supply of crops by increasing yields. Prices are determined by market forces as well as whatever agricultural price support policies are in place. The models use baseline ozone concentrations that are extrapolated to rural areas from both suburban and rural monitors (which generally show similar seasonal average values). While major uncertainties exist in these models, several investigators have used different models and still been fairly consistent in predicting that total annual benefits on the order of $2 billion per year [1985 $] would accrue to consumers and farmers if ozone concentrations in rural areas were reduced by 25 percent.[100] Note, however, that the benefits estimates depend heavily on assumptions about agricultural policies, base year and background ozone concentrations, and the experimental relationships between crop yields and ozone concentrations.

Potential Effects of Ozone on Forests

Ozone-induced injury in trees shows up primarily as foliar injury, including leaf or needle discoloration and premature loss. In extreme cases, leaves and then branches of injured trees die back. Ultimately individual trees can die prematurely. Effects that may not be apparent to the eye include reduced growth rates and increased susceptibility to diseases and other stresses. Reduced photosynthesis and decreased allocation of carbohydrates to tree roots are possible reasons for the increased susceptibility. Controlled experiments suggest that growth rates may be reduced by ozone even though the characteristic visible signs of ozone damage are not present. Weakening of species and premature death of individual trees can have broad ecological impacts, as species which are more resistant to ozone take over. All of these effects, including a transition in dominant species, have been observed in the San Bernardino mountains east of Los Angeles, and attributed to exposure to ozone originating from emissions in the Los Angeles basin.

Many of the effects of exposure to ozone also occur due to numerous other causes. In most cases, it is likely that multiple stresses contribute to observed declines, making it difficult to sort out primary causes or the effect of eliminating or mitigating a single stress. Effects observed in studies that have been conducted in controlled environments in order to isolate the effects of ozone do not always match those observed in natural environments. Moreover, controlled studies have been performed almost exclusively on seedlings or saplings, rather than mature trees. So, while exposure to ozone has been suggested as an explanation for several cases of forest or individual species decline in the United States, Canada and Europe, in most of these cases no consensus exists on the role of ozone.

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[98] Adams et al., 1984.

[99] Kopp et al., 1984.

[100] U.S. EPA, 1987.

Figure 2-11 shows the major forested areas of the United States, and identifies the types of trees that dominate in each area. Comparing Figure 2-11 with Figure 2-9 indicates that elevated ozone concentrations are present in the western conifer region of California, and the eastern hardwood and southeastern yellow pine regions. An additional consideration is that high-elevation forests are likely to be exposed to higher long-term average concentrations than nearby low-elevation forests, due to the tendency for elevated ozone concentrations to be maintained at high altitudes overnight and into the morning, while low-elevation surface concentrations are depleted at night.

Ozone has been suggested as a factor in several confirmed and reported cases of forest or species decline in the United States.[101] Ozone has been implicated as a cause of decline in the first two cases discussed below. It has been suggested as a contributing factor in the other cases.

Ponderosa and Jeffrey pine in the San Bernardino National Forest and other locations in southern California

Ozone is generally held to be a principal cause of visible injury and accelerated mortality of ponderosa and Jeffrey pine and other species in the San Bernardino and San Gabriel Mountains of southern California. The symptoms of injury observed there have been duplicated in controlled exposure studies. At some sites in the San Bernardino National Forest east of Los Angeles, daytime (14 hour) average ozone concentrations of 0.10 ppm are typical during June, July and August.[102] The decline of ponderosa and Jeffrey pine in the national forest has been so severe that if current trends persist, incense cedar and white fir are expected to replace them as the dominant species in the forest.[103] Growth reductions in association with visible foliar injury have also been observed in Jeffrey pine at Sequoia and Kings Canyon National Parks in California.[104]

White pine in the eastern United States

Controlled exposure studies and field studies support the hypothesis that concentrations of ozone widely observed in the eastern United States injure white pine trees,

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[101] NAPAP, 1987.

[102] Ibid.

[103] McBride et al., as cited in NAPAP, 1987.

[104] Peterson et al., 1987.

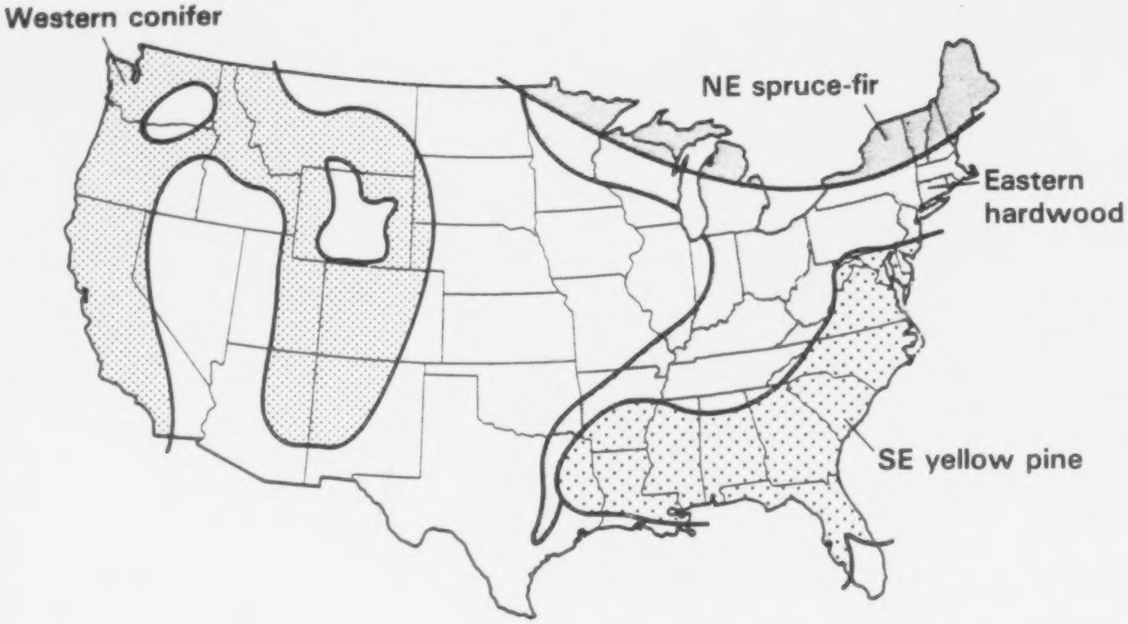

Figure 2-11. Major forested areas and dominant tree-types of the United States [NAPAP, 1987].

although as with other tree species, not all white pines are equally sensitive.[105] Foliar injury, reduced growth rates and increased mortality are apparent in trees throughout the eastern United States.

Red spruce at high elevation sites in the eastern United States

Since the mid 1960's, the number of live red spruce in some high elevation forests in the northeast has decreased by 40 to 70 percent.[106] Decreased radial growth, dieback, and increased mortality have been observed at high elevation sites in the Appalachians from Vermont and New Hampshire to North Carolina, with the highest mortality rates in the northeast.[107] Regionwide trends of colder winters and increasing pollutant levels since about 1960 have both been suggested as explanations.[108] At above-cloud-base sites in remote or rural parts of the eastern United States, nighttime and early morning ozone concentrations are significantly higher than concentrations measured at adjacent sites at lower elevations. The frequent presence of clouds enhances ozone uptake.[109] Scientists suggest that since conditions at high elevations are marginal for red spruce to begin with, the added stresses of colder winter temperatures and/or increased air pollution could readily push high elevation forests into decline.[110]

Yellow pine in the southeastern United States

Average growth rates in natural stands of yellow pine have been reduced by up to 50 percent over rates observed in the late 1950s.[111] The causes of the widespread growth reductions are unknown, but may include the natural aging of the stands, increased competition from hardwoods, drought, and exposure to air pollution. Preliminary results indicate that controlled exposure to ozone has similar effects on loblolly pine as have been observed with other species, including reduced photosynthesis and reduced growth.[112] However, the role of ozone in the yellow pine case has not been firmly established.

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[105] Woodman and Cowling, 1987.

[106] NAS, 1986.

[107] NAPAP, 1987.

[108] NAS, 1986.

[109] NAPAP, 1987.

[110] NAS, 1986.

[111] Sheffield et al., 1985, as cited in NAPAP, 1987.

[112] Heck, 1988.

Sugar maple in Pennsylvania, New York, New England and southeastern Canada

Crown dieback and elevated mortality rates became apparent in stands of sugar maple and associated hardwoods at some locations in southeastern Canada in the late 1970s. Damage has been noticed more recently in the northeastern United States. Pest infestation or disease is the apparent cause in all of the cases in the United States, although some of the cases in Canada cannot be explained.[113] Air pollution has been suggested as a contributing factor. Regionwide average growth rates in the United States have not declined.[114]

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[113] NAPAP, 1987.

[114] Hornbeck et al., 1987, as cited in NAPAP, 1987.

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3. CONTROLLING EMISSIONS

Ozone is not emitted; rather it is produced in the atmosphere from reactions involving two "precursor" pollutants: volatile organic compounds (VOCs) and nitrogen oxides (NO_x). Development of effective control strategies for ozone requires an understanding of the relationship between VOC and NO_x emissions levels and ozone concentrations. It also involves identifying measures to control VOC and NO_x emissions, and determining the levels of reductions that can be achieved and the control costs associated with each measure. In this chapter we discuss (1) the relationship between ozone and its precursors; (2) the sources of VOC emissions and estimates of future emissions levels; (3) the VOC emissions reductions that can be achieved using various control measures and how these compare with levels of reductions required to meet the ozone standard in current nonattainment areas; and (4) the costs of various VOC control measures.

3.1 Relationship of Emissions to Ozone Concentrations

Ozone is produced through chemical reactions of nitrogen oxides (NO_x) and volatile organic compounds (VOCs). Because the chemical reactions depend on both sunlight and temperature, ozone concentrations are highest on hot, sunny days. Nitrogen oxides are products of fossil fuel combustion. On a nationwide basis, approximately 45 percent of NO_x emissions are from motor vehicles and other mobile sources, 30 percent from utilities, and 12 percent from industrial fuel combustion.[1] [2] VOCs are a broad class of organic gases such as vapors from solvents and gasoline. In urban areas, approximately 40 percent of VOCs are emitted from mobile sources, 30 percent from organic solvent use, and smaller fractions from other categories including gas station evaporation, solid waste disposal, chemical manufacturing and petroleum processing.[3] [4]

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[1] National Emissions Data System, Nationwide Emissions Report Summary, computer printout, U.S. Environmental Protection Agency, Research Triangle Park, NC, January, 1988.

[2] NO_x emissions from natural sources are negligible.

The relationship between ozone and its precursors is complex. Reducing emissions of either VOCs or NO_x may or may not produce a decrease in ozone concentrations, depending on the mix of pollutants that is present. Reducing NO_x can even increase ozone concentrations, in some situations. The effect of emissions controls on ozone concentrations depends on meteorological conditions, the absolute and relative amounts of VOCs and NO_x emitted in a particular area, and the background concentrations of ozone and its precursors that are present. Every urban area has a different balance between VOCs and NO_x. Furthermore, day-to-day variability in emissions levels, background VOC and NO_x concentrations and wind patterns leads to day-to-day variations in the balance between VOCs and NO_x in each area. Thus the impact of controls on ozone concentrations will change from day-to-day in a given city, as well as differ across cities. Comparing two different pollution episodes leading to the same peak ozone concentration, the level of VOC emissions reductions required to attain the ozone standard will be highest for the episode that has the higher concentration of VOCs compared to NO_x (i.e. the higher "VOC-to-NO_x" ratio). The converse is true with respect to NO_x controls: the higher the VOC-to-NO_x ratio the higher the efficacy of NO_x reductions.

The impact of controls also depends on the distance between the area where the precursors are emitted and the location where the ozone concentration is monitored. In most areas, observed peak ozone concentrations occur during mid-to-late afternoon, about 30 miles downwind of the center of the city. However, concentrations of ozone that are two-to-three times higher than background levels[5] may be maintained well beyond that distance, affecting suburban and rural areas and also contributing to high concentrations in downwind cities. As the polluted air mass is transported, chemical and physical processes remove NO_x more rapidly than they remove VOCs. Thus in addition to differences in the balance between VOCs and NO_x across days and between different urban areas, for any given pollution episode there can be a substantial shift from relatively NO_x-rich conditions over the downtown area to VOC-rich conditions over downwind suburbs and rural areas. Reducing

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[3] Ibid.

[4] In urban areas, VOC emissions from natural sources are also insignificant. During the summer, in areas which are far from heavy traffic and industrial sources of VOCs, vegetation can be the largest local source of VOC emissions. However, even at their highest levels (in some counties in the southeast during the summer), over equal land areas, estimated VOC emissions from vegetation are only about one-fifth of average urban VOC emissions. Moreover, unless NO_x is also present (from power plants or other industrial sources) ozone will not be produced.

[5] Background ozone concentrations are estimated to peak at about 0.04 ppm (one-hour average).

VOC emissions is apt to be effective in reducing ozone at downtown locations. Reducing NO_x emissions generally becomes more effective in reducing ozone concentrations downwind from high emissions regions, over suburban and rural areas.

EPA has historically encouraged exclusive reliance on VOC emissions controls to ensure compliance with the ambient air quality standard for ozone. NO_x emissions controls have usually been used only to the extent necessary to comply with the standard for nitrogen dioxide. VOC controls have been emphasized for two reasons: (1) control technologies for VOCs have been assumed to be cheaper and more readily available than those for NO_x and (2) there has been concern that reducing NO_x emissions could increase ozone concentrations at some locations.[6] Recent measurements of VOC and NO_x concentrations in a number of areas and extension of modeling analyses to consider the build-up of pollutant concentrations over more than one day, distances further downwind of urban areas, and photochemical pollutants other than ozone, have suggested that in some areas, NO_x controls may be more effective in reducing photochemical pollution than previously thought.[7] [8] [9] [10]

VOC Reductions Required to Meet the Standard

Figure 3-1 presents estimates of VOC emissions reductions needed to reduce local peak ozone concentrations or "design values" down to 0.12 ppm, the maximum concentration allowed under the ozone standard. For areas with design values up to 0.20 ppm, the control requirements shown were estimated using EPA's standard model (the Empirical Kinetic Modeling Approach or EKMA model), with a set of meteorological, emissions and transport conditions selected to approximate conditions in a typical urban area where transport from upwind cities is not the principal cause of nonattainment.[11] A moderate amount of ozone is assumed to be transported from upwind. NO_x emissions are assumed to be unchanged from current levels. The range of estimates given for each design value corresponds to the range of VOC-to-NO_x ratios expected to prevail across different cities with the same design

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[6] Meyer, E.L. Jr., "Review of Control Strategies for Ozone and their Effects on Other Environmental Issues," U.S. Environmental Protection Agency, Research Triangle Park, NC, August 1986.

[7] Bauges, K., "A Review of NMOC, NO_x and NMOC/NO_x Ratios Measured in 1984 and 1985, U.S. Environmental Protection Agency, Report Number EPA-450/4-86-015, Research Triangle Park, NC, September 1986.

[8] Milford, J.B., "Photochemical Air Pollution Control Strategy Development," Ph.D. Thesis, Carnegie Mellon University, Pittsburgh, PA, March 1988.

[9] Sillman, M.S., "Models for Regional-Scale Photochemical Production of Ozone," Ph.D. Thesis, Harvard University, Cambridge, MA, November 1987.

[10] Trainer, M., Williams, E.J., Parrish, D.D., Buhr, M.P., Allwine, E.J., Westberg, H.H., Fehsenfeld, F.C., Liu, S.C., "Models and observations of the impact of natural hydrocarbons on rural ozone," Nature, 329:705-707 (1987).

[11] Meyer, E.L., Jr., personal communication, September, 1987.

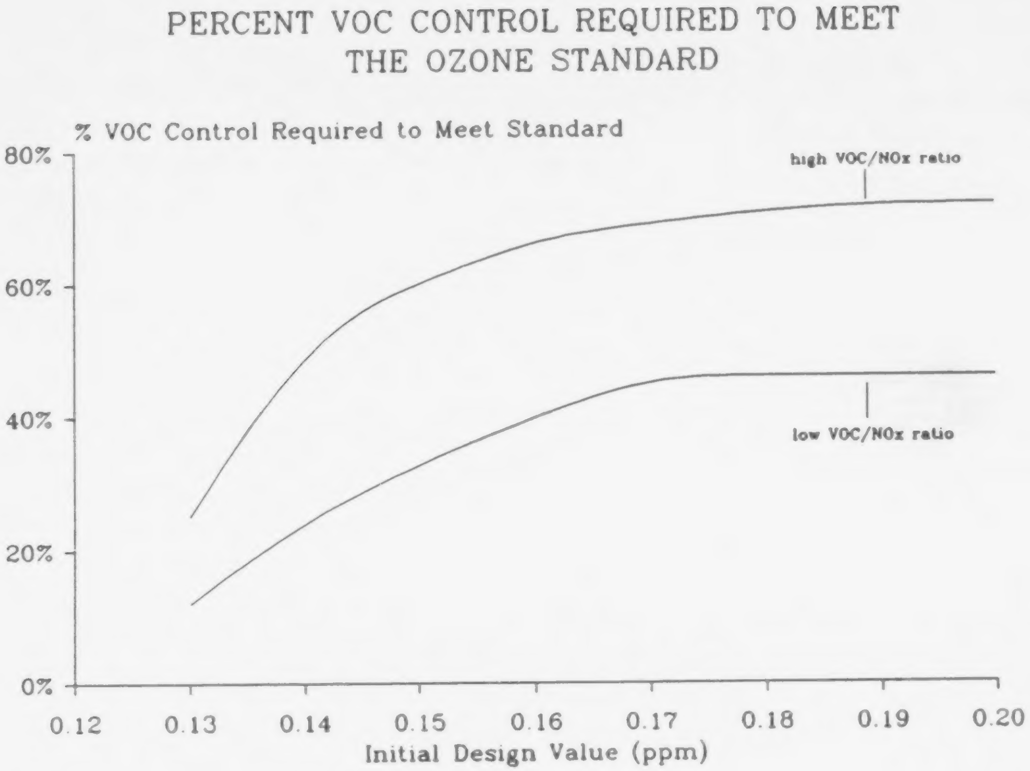

Figure 3-1. VOC emissions reductions estimated to be required to reduce ozone from the initial peak concentrations or "design values" shown down to 0.12 ppm. The control requirements were estimated using EPA's standard model, with meteorological, emissions and transport conditions set to approximate conditions in a typical area where transport from upwind cities is not the principal cause of nonattainment. The range of estimates shown for each design value corresponds to the range of VOC and NO_x ratios expected to prevail across different cities. The percentage reduction needed to meet the standard in an individual city will typically fall somewhere between the two curves shown.

value.[12] The estimates shown in Figure 3-1 are for reducing peak ozone concentrations at monitors that are about 30 miles downwind of an urban center. Situations involving transport to rural areas or other cities further than about 30 miles downwind will be discussed later.

To illustrate how to interpret Figure 3-1, the model predicts that for a typical city with a design value of 0.16 ppm, with no change in NO_x emissions levels, VOC reductions ranging from about 45 to 70 percent will be needed to meet the ozone standard. For areas where current conditions are usually NO_x-rich (e.g. an ambient VOC-to-NO_x ratio of about 8:1 or lower), the VOC reductions required to reduce local ozone concentrations are expected to be at the lower end of the ranges shown. Where conditions are predominantly VOC-rich (e.g. an ambient VOC-to-NO_x ratio of about 15:1 or higher), control requirements are expected to fall at the upper end of the range. Generally, the level of VOC control required to meet the standard locally will be highest for those areas with the highest design values and the most VOC-rich conditions.

Interim Reductions: The Effect of Lowering VOC Emissions by 35 Percent

As we will discuss later, if all of the controls we were able to analyze were to be imposed, the total reduction in VOC emissions estimated for most areas would be between 20 and 40 percent, falling short of the levels estimated to be required to attain the standard in many cities. Figure 3-2 shows the ozone concentrations predicted to result when VOC emissions are reduced by 35 percent (with NO_x emissions unchanged), plotted against initial design values. The three solid lines represent estimates of final ozone concentrations expected to result from a 35 percent reduction in VOC emissions with no change in NO_x emissions, if controls are applied in cities with low (8:1), medium (12:1) and high (15:1) VOC-to-NO_x ratios. The dashed line illustrates "no change" in ozone concentrations, i.e. the final concentration is the same as the initial concentration or design value. Note that the ozone standard, 0.12 ppm, is at the bottom of the graph, so that the relative position of a control scenario line between the "no change" diagonal and the bottom of the graph indicates what fraction of the reduction in ozone needed to obtain the standard is predicted to be achieved. For example, if a city has a medium VOC-to-NO_x ratio and a design value of 0.16 ppm, a 35 percent reduction in VOC emissions is predicted to yield a final ozone concentration of about 0.14 ppm, or about half of the reduction estimated to be required to meet the standard.

VOC reductions obtainable from the control measures we analyzed should be sufficient to enable most areas with design values of 0.13 ppm to meet the standard. Areas with design values of 0.14 ppm and low VOC-to-NO_x ratios should also be able to attain the standard.

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[12] Bauges, op. cit., footnote 7.

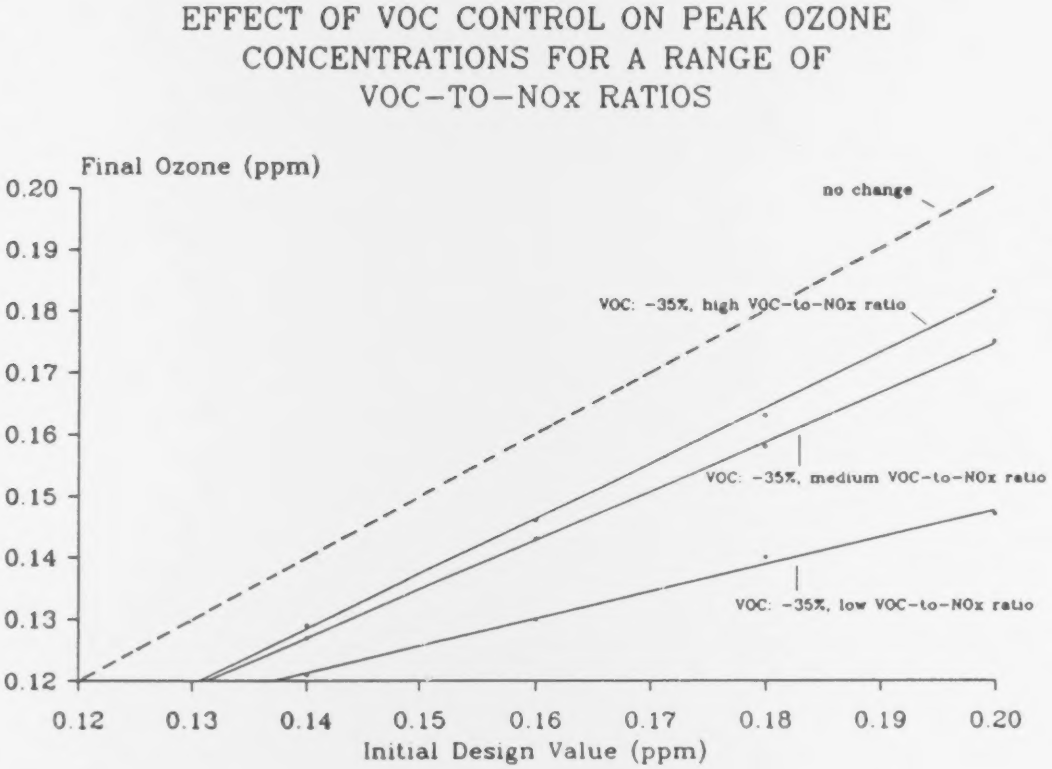

Figure 3-2. Ozone concentrations predicted to result when VOC emissions are reduced by 35 percent, with no change in NO_x emissions levels. The three solid lines indicate the ozone concentrations predicted to result in cities with low, medium and high VOC to NO_x ratios. The dashed line illustrates the "no control" case, i.e. the final ozone concentrations are the same as the initial design values.

The reductions we could quantify would be expected to get areas with higher design values and low VOC-to-NO_x ratios more than half way to the standard, in terms of the ozone reductions they need. Areas with medium to high VOC-to-NO_x ratios are predicted to get less than a third of the reductions they need.

Interim Reductions: The Effect of Adding NO_x Controls

Figure 3-3 shows the effect of reducing NO_x emissions as well as VOCs. Figure 3-3a shows the effect of adding NO_x controls to VOC controls in cities with medium VOC-to-NO_x ratios; Figure 3-3b in areas with low VOC-to-NO_x ratios; and Figure 3-3c in areas with high VOC-to-NO_x ratios. Each of these three figures provides reasonable estimates of the effect that reducing VOCs and NO_x would have on local peak ozone concentrations in roughly a third of the areas that are not meeting the ozone standard.

As shown in Figure 3-3, the model predicts that for most cities, 35 percent reductions in both NO_x and VOC emissions would reduce ozone concentrations more than 35 percent reductions in VOCs alone. In fact, the combination is predicted to result in attainment in some cities -- namely those with low design values and relatively high VOC to NO_x ratios, that would not be predicted to meet the standard if only VOC emissions were to be reduced.

In urban areas with low VOC-to-NO_x ratios and high design values, the model predicts that ozone concentrations would be higher if both VOC and NO_x emissions were reduced by 35 percent than if only VOC emissions were reduced (Figure 3-3b). This result suggests that NO_x controls could be counterproductive for major urban areas that are characterized by low VOC-to-NO_x ratios and high design values -- such as Baltimore, Boston, Los Angeles, Philadelphia and Washington.[13] [14] However, a complicating issue in Los Angeles is that NO_x controls are expected to be needed to significantly reduce ozone concentrations at some locations within the air basin, whereas to reduce ozone at other sites VOC controls are predicted to be needed and NO_x controls to be counterproductive.[15] [16] NO_x controls are a major thrust of strategies for reducing ozone in the Los Angeles basin. This same issue may be important in other places with high design values and low characteristic VOC-to-NO_x ratios where the ozone standard is exceeded over a large area (e.g. along the northeast corridor). However, for areas other than Los Angeles, we lack sufficient information to determine what combination of VOC and NO_x controls might be desirable.

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[13] Ibid.

[14] Bauges, K., personal communication, October 1987.

[15] Milford, op. cit., footnote 8.

[16] South Coast Air Quality Management District, "Air Quality Management Plan, 1982 Revision, Appendix No. VI-A, Ozone Analysis for the South Coast Air Basin," El Monte, CA, October 1982.

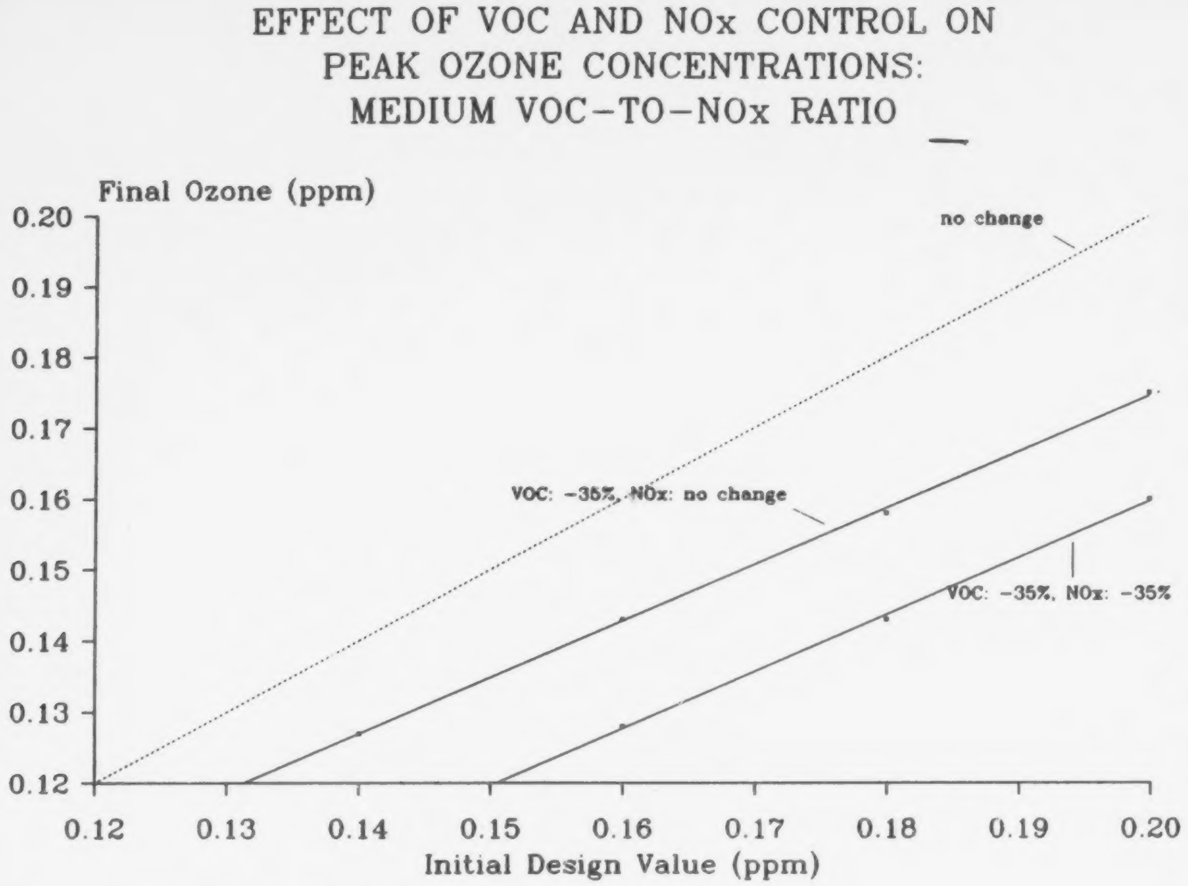

Figure 3-3. Ozone concentrations predicted to result when VOC emissions are reduced by 35 percent alone or in combination with 35 percent reductions in NO_x emissions. Figure 3-3a shows estimates for cities with medium VOC-to-NO_x ratios, Figure 3-3b cities with low VOC-to-NO_x ratios and Figure 3-3c cities with high ratios. Roughly one-third of the ozone nonattainment areas are thought to be represented by each figure. The dashed line in each figure illustrates the "no control" case, i.e. the final ozone concentrations are the same as the initial design values. The solid lines in each figure show results with 35 percent reductions in VOC emissions together with 0 and 35 percent reductions in NO_x. In areas with medium and high VOC-to-NO_x ratios (Figures 3-3a and 3-3c), ozone concentrations are predicted to be further reduced when NO_x controls are added to VOC emissions reductions. In areas with low VOC-to-NO_x ratios (Figure 3-3b), however, ozone concentrations are predicted to be reduced to the greatest extent by controlling VOC emissions alone, with NO_x emissions reductions of up to 35 percent predicted to be counterproductive.

EFFECT OF VOC AND NOx CONTROL ON PEAK OZONE CONCENTRATIONS: LOW VOC-NOx RATIO

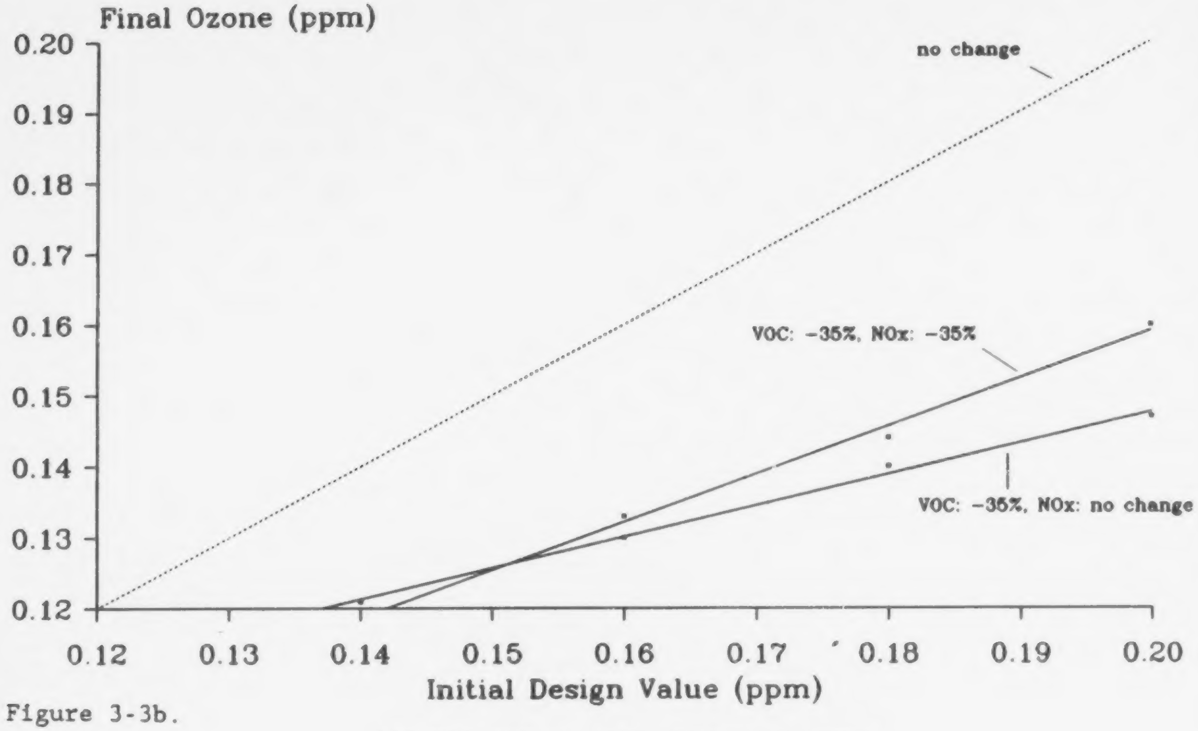

Figure 3-3b.

HIGH VOC-TO-NOx RATIO

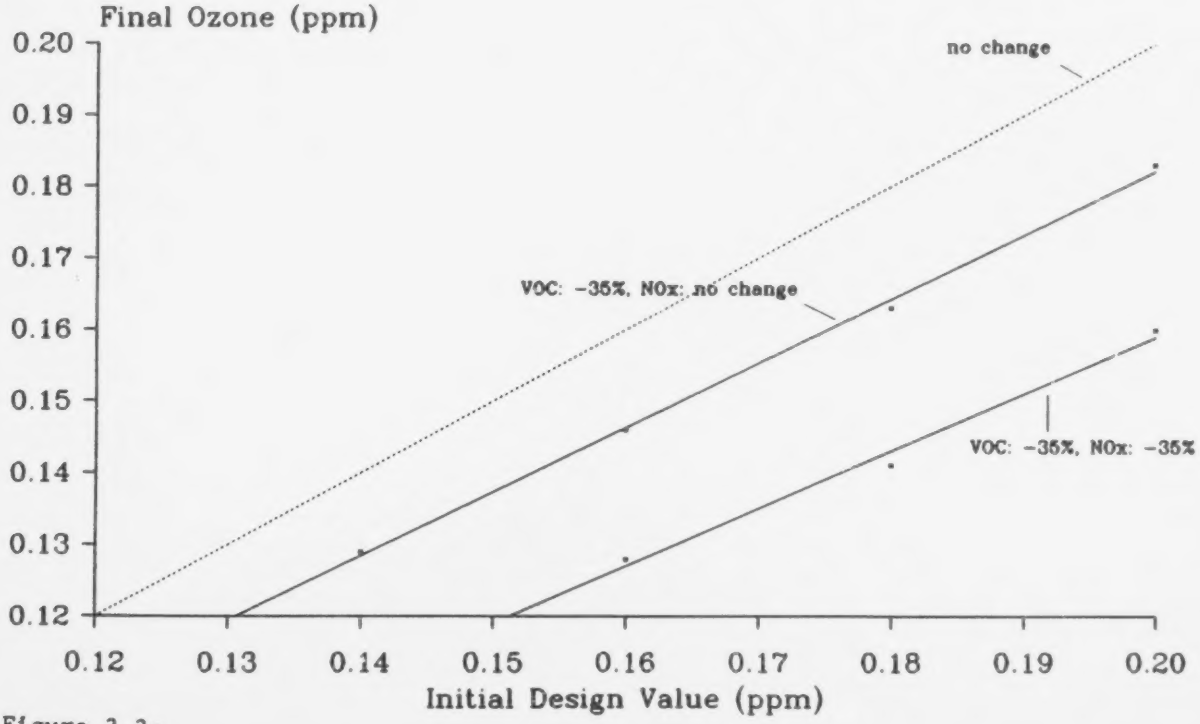

Figure 3-3c.

In general, where high ozone concentrations occur closer to the urban center than assumed for Figures 3-1 through 3-3, VOC controls are expected to be more effective, and NO_x controls less effective, than illustrated above.[17] [18] [19] Where high ozone concentrations occur further downwind than assumed for Figures 3-1 through 3-3, VOC controls are expected to be less effective, and NO_x controls more so, than shown.[20] [21]

Situations Involving Transport of Ozone or its Precursors

Transport of ozone and precursors from upwind cities can complicate efforts to attain the ozone standard. Moreover, ozone concentrations in nonurban areas may approach or even exceed 0.12 ppm over an hour or more during the day due to transport from upwind cities. Elevated ozone concentrations in rural areas are of concern due to forest and crop damage that may result, in addition to potential health effects.

During the day, due to transport, elevated concentrations of ozone can occur over areas up to about a hundred miles downwind of urban areas, causing violations of the ozone standard in relatively sparsely populated, nonindustrial areas. At night, ozone and VOCs can be transported over distances of 200 miles or more.[22] Polluted air that has been carried at high altitudes over night mixes with air at the surface during the first few hours after sunrise (as ground-level temperatures increase).[23] Finally, in association with large-scale high pressure systems that maintain clear skies and elevated temperatures, pollution episodes can last for several days and cover multi-state regions.[24] During these episodes, which occur over the eastern United States several times each summer,[25] [26] elevated ozone concentrations over both urban and rural areas can arise from a combination of transport and fresh emissions that enter the system as it moves, and due to the maintenance of conditions ripe for ozone formation.

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[17] Meyer, op. cit., footnote 6.

[18] Milford, op. cit., footnote 8.

[19] Dodge, M.C., "Chemistry of Oxidant Formation: Implications for Designing Effective Control Strategies," Proceedings, North American Oxidant Symposium, Quebec, Canada, February 1987.

[20] Meyer, op. cit., footnote 6.

[21] Milford, op. cit., footnote 8.

[22] Spicer, C.W., Joseph, D.W., Sticksel, P.R., Ward, G.F., "Ozone sources and transport in the northeastern United States," Environmental Science and Technology, 13:975-985 (1979).

[23] Note that due to dilution and chemical reactions, the ozone transported into an area is not simply added to the concentration which would otherwise be produced (e.g. 0.10 ppm transported into an urban area in the morning might only contribute about 0.05 ppm to the peak ozone concentration observed that day.)

[24] Vukovich, F.M., Bach, W.D. Jr., Crissman, B.W., King, W.J., "On the relationship between high ozone in the rural surface layer and high pressure systems," Atmospheric Environment, 11:967-983 (1977).

[25] Samson, P.J., Ragland, K.W., "Ozone and visibility in the midwest: evidence for large-scale transport," J. Applied Meteorology, 16:1101-1106 (1977).

[26] Vukovich et al., op. cit., footnote 24.

Transport of ozone and its precursors downwind of source areas on the same day the precursors were emitted is thought to be the most frequent cause of "rural" nonattainment. It can also compound ozone problems in urban areas downwind of the original source regions. Transport on this scale exacerbates nonattainment problems of cities along the northeast corridor from Virginia to Maine; along the Gulf Coast of Texas and Louisiana; and in California. Transport that occurs over night or during regional-scale episodes also exacerbates nonattainment problems in many cities. Although not typically leading to violations of the ozone standard in rural areas, overnight transport and regional-scale episodes are thought to account for a significant portion of the ozone measured at rural sites.

NO_x controls in upwind cities are generally expected to be more effective than VOC controls at lowering ozone concentrations in *rural* areas downwind.[27] Both VOC and NO_x controls in upwind areas may be effective for reducing the contribution of transport to ozone problems in downwind *urban* areas, because both transported ozone and transported VOCs can be important.

3.2 Volatile Organic Compounds: Characterization of Current and Future Emissions

This section describes the sources of volatile organic compound (VOC) emissions and presents our estimates of the changes in emissions over the next 15 years due to the offsetting influences of economic growth and State and federal regulations in place as of 1987. These estimates serve as a baseline for considering the effects of regulatory changes needed to attain the ozone standard.

Sources of Volatile Organic Compounds

Table 3-1 displays estimates of 1985 VOC emissions, number of cities, and population within each of five ozone design value categories. The EPA 1985 National Emissions Data System (NEDS) inventory is the source of our emissions data and serves as the base inventory for all future year projections presented in this report. Of the 19 million tons of VOCs

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[27] NO_x controls are also expected to be required to reduce ozone produced locally in rural areas where VOCs from vegetation react with NO_x from power plants and other industrial sources [Trainer et al., 1987].

Table 3-1. SUMMARY OF 1985 VOC EMISSIONS IN NONATTAINMENT CITIES AND ATTAINMENT REGIONS

	VOC Emissions (1000 tons)[a]	Percent Stationary (%)	Percent Mobile (%)	No. of Cities	1985 Population (millions)
Nonattainment Cities by Design Value Category (in ppm O_3)					
0.13-0.14	2,200	62	38	37	30.2
0.15-0.17	3,600	61	39	40	55.3
0.18-0.26	1,100	63	37	14	20.2
> 0.26	770	56	44	3	11.9
Total (nonattainment)	7,700	61	39	94	117.7
Attainment Regions	11,000	62	38		118.8
TOTAL	19,000	61	39		236.5

Source: EPA 1985 National Emissions Data System emissions inventory, January 1988 printout; population data from Bureau of Census.

[a] Totals are rounded.

emitted per year, nationwide, approximately 40 percent were generated in 94 cities that exceeded the ozone standard during the 1983 to 1985 period[28]. These regions contain about half of the nation's population.

Figure 3-4 displays the percent contribution of various source categories to the total 1985 VOC emissions. About two-thirds of the emissions are generated from two main categories: mobile sources and organic solvent evaporation from stationary sources. About 30 percent of the 1985 emissions inventory is composed of highway vehicle emissions. A further breakdown of the data, shown in Figure 3-5, reveals that passenger cars are the largest contributors within the highway vehicle category, with almost 20 percent of the total 1985 VOC emissions, followed by light-duty gasoline trucks with eight percent.

Organic solvent evaporation from stationary sources contributed almost 30 percent of the total VOC emissions in 1985. The sources within this category are extremely varied and include such activities as degreasing of metal parts and products, dry cleaning, printing, and surface coating. The range of individual source sizes (as defined by their individual annual VOC emission rates) can also be quite wide, ranging from a small gas station degreasing tank that emits less than a ton per year, to large industrial operations that contain evaporation sources emitting several hundred tons per year. Figure 3-4 shows that solvent evaporation from small stationary sources emitting less than 50 tons per year contributes about 25 percent of total VOC emissions.

Figure 3-6 displays the breakdown of stationary source emissions by source size. About half of the total 1985 VOC emissions originated from stationary sources that emit less than 50 tons per year. Because of the way EPA constructs the NEDS emissions inventory, it is not possible to show, with much certainty, a more detailed breakdown of the "less-than-50 tons-per-year" size class.[29] However, we do know that *at least* two percent of the inventory comes from sources emitting between 25 and 100 tons per year, and that this contribution *could* be as high as 30 to 40 percent. We have chosen 18 percent as a "rough guess",

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[28] For our analysis, an area is considered in nonattainment if its design value is greater than 0.12 ppm ozone according to EPA-published 1983-1985 ozone monitoring data. EPA's actual determination of nonattainment is based on a slightly different method, but the resulting number of nonattainment cities are essentially the same. Our number of nonattainment areas differs from EPA's count of 61 because, in several cases, EPA has used Consolidated Metropolitan Statistical Areas (CMSAs), rather than cities. Several of these CMSAs include two or more cities that we have considered separately.

[29] EPA requires States to report VOC emissions from individual sources that emit more than 50 tons per year. If a large "facility" (that contains more than one source) emits more than 100 tons per year of VOCs, each individual source emitting more than 25 tons per year *within* that facility must also be reported. EPA uses a "market-balance" approach to indirectly estimate the aggregate remaining emissions from small sources that are not required to report their emissions. Determination of individual source sizes is, therefore, not possible for these small size categories.

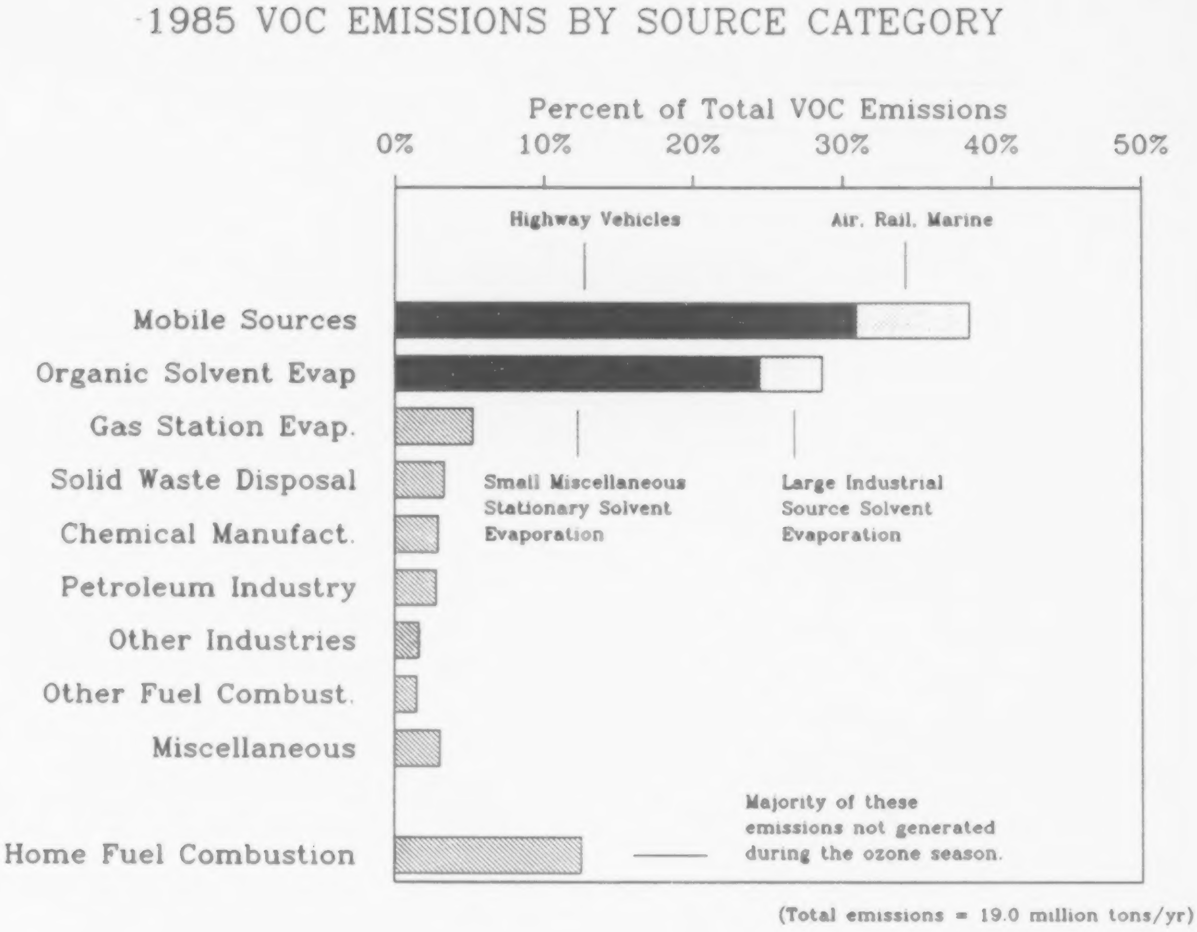

Figure 3-4. Volatile Organic Compound (VOC) Emissions by Source Category in 1985. Source: OTA, from EPA's National Emissions Data System (NEDS)

Note: Under the category "Organic Solvent Evaporation," the subcategory "Small Miscellaneous Stationary..." includes only sources that individually emit less than 50 tons per year of VOC.

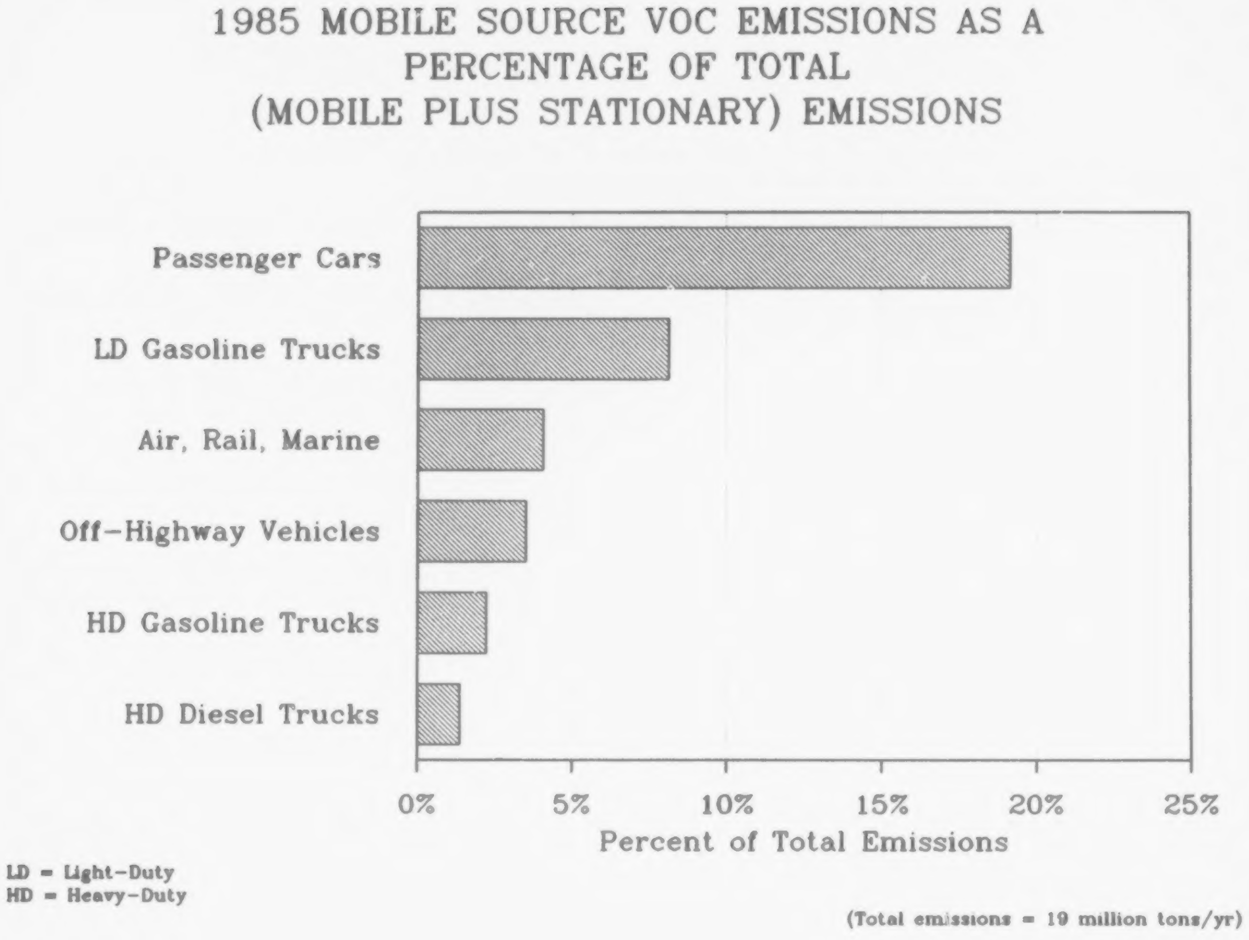

Figure 3-5. Volatile Organic Compound Emissions from Mobile Sources as a Percentage of Total (Mobile plus Stationary) Emissions in 1985.

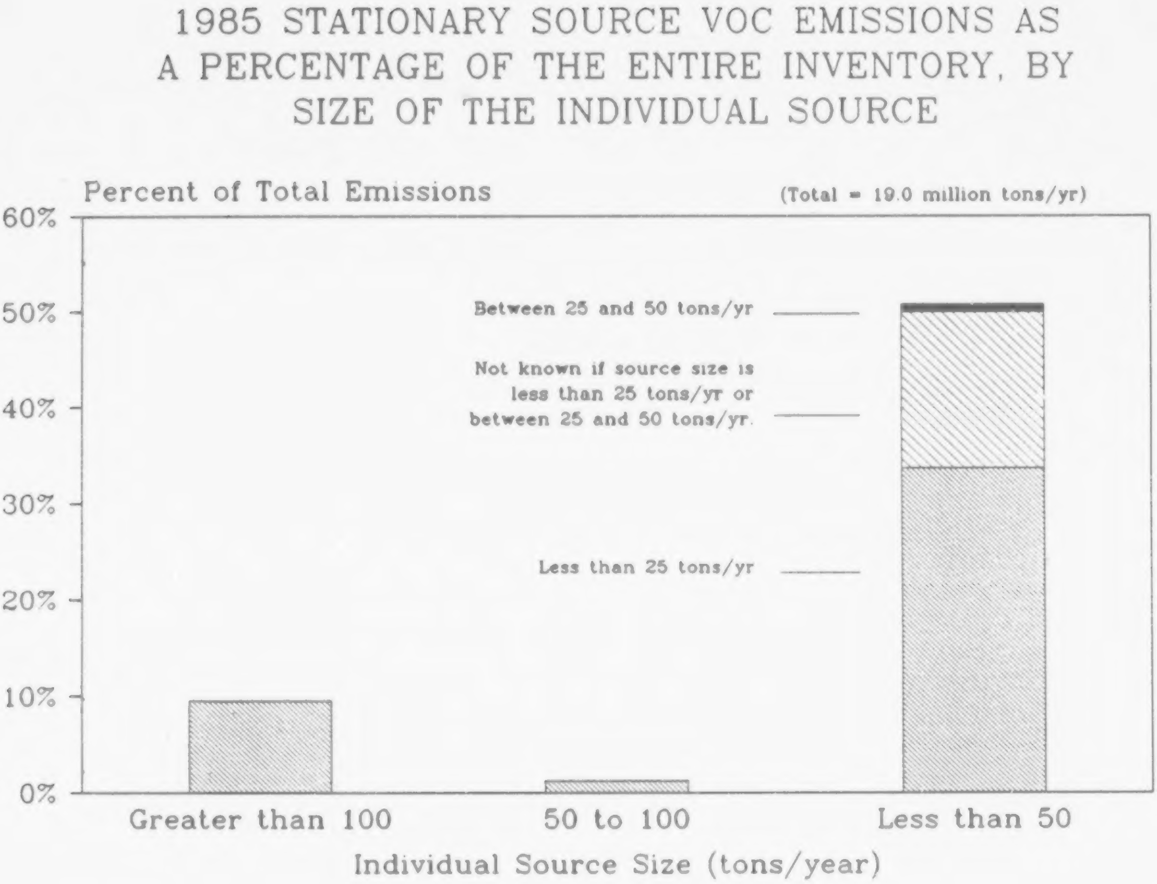

Figure 3-6. Stationary Source Emissions of Volatile Organic Compounds (VOCs) as a Percentage of the Total Emissions Inventory, By Size of the Individual Source.

Each bar displays the percentage of total VOC emissions that are contributed by each source-size class. For example, about 50 percent of total emissions come from sources that emit less than 50 tons per year. Because of the way the 1985 emissions inventory is constructed, we are unable to give a more precise detailed breakdown within the "Less-than-50 tons-per-year" category. We have assumed that sources that emit between 25 and 100 tons per year account for about 18 percent of the total VOC emissions; this percentage could be as high as 30 to 40 percent.

assuming that about a third of the small aggregated VOC stationary sources in the inventory (for which no source size can be identified) may, individually, emit more than 25 tons per year.[30] The uncertainty about the actual sizes of the less-than-50-ton sources does not diminish the significant contribution they make to total VOC emissions.

It is important to highlight potentially significant sources of VOC that do *not* appear in the 1985 NEDS emissions inventory. Treatment, storage, and disposal facilities (TSDF's) are now considered important sources, and will very likely appear in future VOC inventories. Biogenic sources (e.g., trees and other vegetation) have also been recognized as a potentially important VOC source category. However, biogenic sources are generally considered to have little influence on local generation of *urban* ozone.

Finally, it is important to recognize that all emission inventories have an inherent, unquantified, level of uncertainty. Given this drawback, any interpretation of emissions inventory data, including those presented in this report, must be made with caution.

Future VOC Emissions

Tables 3-2 through 3-4 display our projections of VOC emissions in 1993, 1998, and 2003, assuming that existing State and EPA regulations do not change. These projections serve as a baseline from which to gauge the effectiveness of future regulations; for example, the changes proposed in recent Congressional bills or EPA's proposed post-1987 ozone policy. Under current regulations, total VOC emissions would decline by approximately five percent from 1985 levels by 1993, and three percent from 1985 levels by 1998. However, total emissions are expected to start increasing again sometime after 1998, showing a net increase of two percent in 2003 from 1985 levels.

The net decrease in VOC emissions between 1985 and 1998 is due to lower emission rates from cars and trucks.[31] Although the number of vehicle-miles travelled is forecast to increase in many areas over this period, the gradual replacement of current vehicles with newer, cleaner ones will result in an overall decline in highway vehicle emissions. Figure 3-7 shows mobile and stationary source VOC emissions through time. VOC emissions from highway vehicles are projected to decline by about 44 percent between 1985 and 1998.

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[30] The 25-ton-per-year size cutoff was chosen so that we could analyze (in a later section) the emissions reduction potential from stationary sources greater than 25 tons per year. The Clean Air Act currently requires that, at a minimum, all stationary VOC sources that emit more than 100 tons per year in nonattainment areas must adopt "reasonably available" control methods, though this cutoff is lower for some categories.

[31] Future highway vehicle emissions were projected using EPA estimates of future highway vehicle VOC emission rates, combined with estimates of average yearly miles-travelled per person, and Census Bureau population projections.

Table 3-2. SUMMARY OF 1993 VOC EMISSIONS IN NONATTAINMENT CITIES AND ATTAINMENT REGIONS (Emissions in 1000 tons per year)[a]

	VOC Emissions			Change from 1985 Emissions		
	Total	Stationary	Mobile	Total	Stationary	Mobile
Nonattainment Cities by Design Value Category (in ppm O_3)						
0.13-0.14	2,100	1,500	570	-7%	8%	-32%
0.15-0.17	3,400	2,400	980	-6%	10%	-31%
0.18-0.26	1,100	800	300	-3%	12%	-28%
> 0.26	720	490	230	-6%	14%	-31%
Total (nonattain.)	7,300	5,200	2,100	-6%	10%	-31%
Attainment Regions	11,000	7,600	3,200	-4%	9%	-27%
TOTAL	18,000	13,000	5,300	-5%	9%	-28%

[a] Totals are rounded.

Table 3-3. SUMMARY OF 1998 VOC EMISSIONS IN NONATTAINMENT CITIES AND ATTAINMENT REGIONS (Emissions in 1000 tons per year)[a]

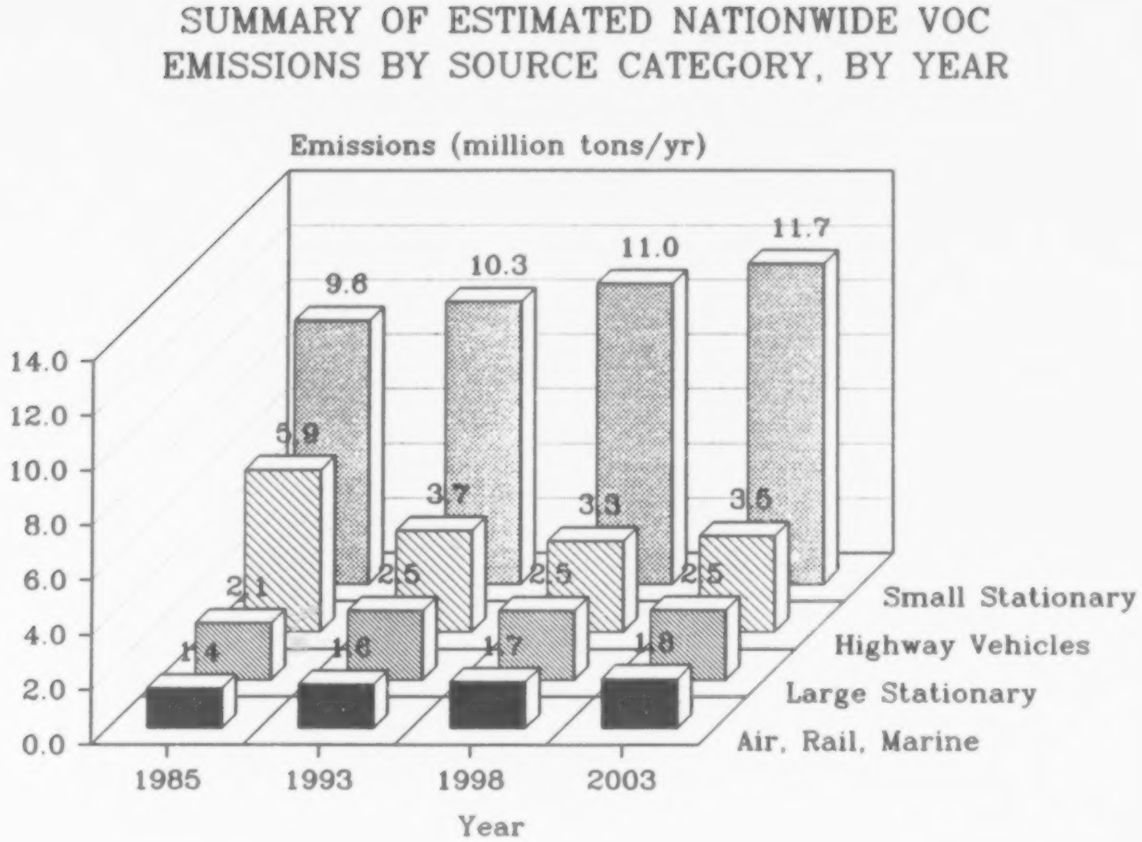
	VOC Emissions			Change from 1985 Emissions		
	Total	Stationary	Mobile	Total	Stationary	Mobile
Nonattainment Cities by Design Value Category (in ppm O_3)						
0.13-0.14	2,100	1,500	530	-6%	13%	-38%
0.15-0.17	3,500	2,600	920	-4%	16%	-35%
0.18-0.26	1,100	850	280	0%	19%	-32%
> 0.26	750	530	220	-2%	23%	-35%
Total (nonattain.)	7,400	5,500	1,900	-4%	16%	-36%
Attainment Regions	11,000	8,000	3,000	-2%	15%	-30%
TOTAL	18,000	13,000	5,000	-3%	15%	-32%

[a] Totals are rounded.

Table 3-4. SUMMARY OF 2003 VOC EMISSIONS IN NONATTAINMENT CITIES AND ATTAINMENT REGIONS (Emissions in 1000 tons per year)[a]

	VOC Emissions			Change from 1985 Emissions		
	Total	Stationary	Mobile	Total	Stationary	Mobile
Nonattainment Cities by Design Value Category (in ppm O_3)						
0.13-0.14	2,200	1,600	550	-2%	18%	-35%
0.15-0.17	3,700	2,700	970	2%	23%	-32%
0.18-0.26	1,200	900	300	7%	27%	-30%
> 0.26	800	570	230	5%	34%	-32%
Total (nonattain.)	7,900	5,800	2,000	2%	23%	-32%
Attainment Regions	12,000	8,400	3,200	3%	21%	-25%
TOTAL	19,000	14,000	5,300	2%	21%	-28%

[a] Totals are rounded.



Note:
"Small Stationary" = sources less than 50 tons/yr.

Figure 3-7. Summary of Estimated Nationwide Volatile Organic Compound Emissions by Source Category, by Year.

The numbers directly above the boxes are the total emissions within the source category. For example, emissions from Highway Vehicles in 1993 are 3.7 million tons per year.

Stationary source emissions, on the other hand, are forecast to increase steadily between 1985 and 2003, showing a nine percent increase by 1993 and a 21 percent increase by 2003, over 1985 levels.[32] Small (less than 50 ton-per-year) stationary VOC source growth is one of the most important reasons why overall VOC emissions are not expected to decline more rapidly in the earlier years and why total emissions may show a net *increase* by 2003. This source category effectively offsets much of the emissions reductions realized from highway vehicles.

Our projections for large stationary source emissions may be somewhat high because we are unable to explicitly model all of the control requirements in the Clean Air Act pertaining to new and modified large VOC emission sources in nonattainment areas.[33] However, the effect on our overall emissions estimates is small because, as illustrated in Figure 3-7, small stationary source growth will have a much more significant impact on future estimates of total VOC emissions than large stationary sources. In most States, these more stringent new source regulations do not apply to small sources.

As discussed in the next section, changes in VOC emissions due to the source-specific regulations currently in place are not sufficient to attain the standard in most nonattainment cities. In a following section, we discuss the reductions necessary to attain the ozone standard, as required under the Clean Air Act, and the reduction potential of additional source-specific controls.

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[32] Future large stationary source (greater than 50 tons per year) emissions were estimated using projections of industrial employment growth within various industrial categories, while small source growth was based either on industrial employment, estimates of population growth, or growth in the Gross National Product per capita. References used included:

David South, et al., Argonne National Laboratory, "Industrial VOC Model: Regionalized Forecasts of Uncontrolled Emissions by Source Category, Draft Discussion Paper No. 19 for Task Group B of the Interagency Task Force on Acid Precipitation," prepared for U.S. Department of Energy, Office of Planning and Environment, Washington, D.C., June 1985.

U.S. Department of Commerce, Bureau of Economic Analysis, *Survey of Current Business* (Washington, DC: U.S. Government Printing Office, October 1985), pp. 32-36.,U.S. Department of Commerce, Bureau of the Census, *Statistical Abstracts of the United States, 1981* (Washington, DC: U.S. Government Printing Office, 1987), p. 14.

U.S. Department of Commerce, Bureau of Economic Analysis, *Survey of Current Business* (Washington, DC: U.S. Government Printing Office, July 1987), pp. 78.

[33] These regulations require that new stationary sources with the potential to emit more than 100 tons per year install the most stringent emission controls possible and that VOC emissions from other existing sources in the area be reduced so that there will be a net *decline* in emissions after new operations commence. These same control requirements apply to major modifications of existing sources that result in a VOC emissions increase of more than 40 tons per year.

3.3 Potential Emissions Reductions From Control Strategies Analyzed by OTA

In this section we analyze the VOC emissions reductions from, and costs of, source-specific control strategies currently being considered by the Congress and EPA. We also show how these potential emissions reductions compare with estimates of the overall emissions reductions needed to attain the ozone standard in each nonattainment city. Discussion of the costs of these control strategies appears in Section 3.5.

We are able to analyze the following source-specific control strategies:

- "Reasonably Available Control Technology" (RACT) on all existing stationary sources;
- Adoption of new "Control Technique Guidelines" (CTG's) for several existing stationary sources of VOC;
- Establishment of new federally-regulated controls on selected stationary VOC sources;
- "Onboard" technology on motor vehicles to capture gasoline vapor during refueling;
- "Stage II" control devices on gas pumps to capture gasoline vapor during motor vehicle refueling;
- Inspection and maintenance (I/M) programs for highway vehicles;
- More stringent exhaust emission standards for gasoline highway vehicles;
- New federal restrictions on fuel volatility; and
- The use of methanol instead of gasoline as a fuel for vehicles in centrally-owned fleets.

Transportation control measures that limit motor vehicle use are potentially important control strategies that we are unable to analyze at this time.

Throughout the analysis, emissions reductions reported apply to the change occurring between 1985 and the relevant future year. The emissions reductions reported in our analysis result from currently available control methods that we know can be applied in the near-term. We were able to analyze the emissions reduction potential and associated control costs for strategies applicable to about three-quarters of current VOC emissions. The remaining one-quarter[34] of VOC emissions primarily come from stationary sources for which we either could not find applicable control technologies or that we could not analyze because of a lack of suitable information. We believe that the large majority of emission reductions possible with currently available control methods are accounted for in our analysis. This does not imply that additional VOC reductions beyond those analyzed here are not possible, but that they should not be counted on within the next five to 10 years.

All control strategies listed above apply to nonattainment cities. Strategies including federal controls on selected small VOC stationary sources, Onboard controls, more stringent highway vehicle standards and fuel volatility limitations apply nationwide, not just in nonattainment cities. It should be noted that both S.1894 and H.R.3054 require *some* VOC control in selected attainment areas in States designated as ozone transport regions. However, because each Congressional proposal sets up slightly different transport regions, we have chosen to exclude these areas from our analysis.

Tables 3-5 through 3-7 present estimates of emissions reductions achieved in 1993, 1998, and 2003, respectively, if the various control strategies listed above are applied. We estimate that VOC emissions in nonattainment cities can be reduced by 1.7 million tons per year in 1993, about 21 percent below 1985 levels. Because some measures are not restricted to nonattainment areas, approximately 2.7 million tons per year would be eliminated nationwide. By 2003, total emissions reductions from these control measures in nonattainment areas increase only slightly to about 1.9 million tons per year.[35]

Again, we must stress that these estimates are for emissions reductions from the additional controls that we are able to analyze. The remaining one-quarter of the inventory that we were unable to analyze may contain emissions that could have been reduced by applying some of these strategies. Therefore, actual emissions reduction potential available from these additional controls may be greater than represented here. Other potential control strategies, such as transportation control measures, are not included in our analysis.

Figures 3-8 and 3-9 display our estimates of emissions reductions resulting from each control strategy in 1993 and 2003, as a percentage reduction below total 1985 emissions in nonattainment cities. The largest reductions come from instituting RACT on stationary sources and limiting fuel volatility. The percentage reductions are about the same for most

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[34] Emissions from treatment, storage, and disposal facilities are not included in this fraction since they were not included in EPA's 1985 National Emissions Data System (NEDS) emissions inventory.

[35] Note that the total reductions are slightly lower than the sum of the component categories. This is because the emissions reductions achieved by (a) lowering fuel volatility in combination with an I/M program, and (b) combining a Stage II and Onboard control program, are slightly less than instituting each one alone.

Table 3-5. Potential Emissions Reductions in 1993 Compared to 1985 Emissions From Source-Specific Control Strategies (Emissions in 1000 tons per year)[a]

	RACT	New CTG's	Federal Controls	Onboard	Stage II	Combined Stage II & Onboard	Fuel Volatility Control[b]	Enhanced I/M	New Highway Vehicle Emis. Stds	Methanol Fuels	ALL CONTROLS[c]
Nonattainment Cities by Design Value Category (in ppm O_3)											
0.13-0.14	120	17	61	22	62	63	150	78	7	0	470
0.15-0.17	240	26	110	38	100	110	230	110	12	0	820
0.18-0.26	77	5	37	12	30	35	59	33	4	12	250
> 0.26	21	6	28	8	0	24	0	28	3	10	120
Total (nonattain.)	460	54	240	81	190	230	440	250	27	22	1,700
Attainment Areas	0	0	220	87	0	87	710	0	36	0	1,000
TOTAL	460	54	460	170	190	320	1,200	250	63	22	2,700

[a] Totals are rounded.

[b] Estimates are equivalent annual reductions. Actual reductions are required only five months out of the year.

[c] "All Controls" include RACT, new CTG's, federal controls, combined Stage II and Onboard, gasoline volatility controls, enhanced I/M, and new mobile emission standards. Note that total reductions are slightly lower than the sum of each component category. This is because the reductions achieved by lowering gasoline volatility in combination with an enhanced I/M program, and a combining Stage II and Onboard program, are slightly lower than instituting each one alone.

Strategy Descriptions:

RACT = "Reasonable Available Control Technology" on all existing stationary sources that emit more than 25 tons per year of VOC.
New CTG's = new Control Technique Guidelines for existing stationary sources that emit more than 25 tons per year of VOC.
Federal Controls on selected small stationary sources of VOC (consumer and commercial solvents, and architectural surface coatings).
Onboard controls on motor vehicles to capture gasoline vapor during refueling.
Stage II control devices on gas pumps to capture gasoline vapor during motor vehicle refueling.
Fuel volatility controls which limit the rate of gasoline evaporation.
Enhanced inspection and maintenance (I/M) programs for cars and light-duty trucks.
New highway-vehicle emission standards for passenger cars and light-duty gasoline trucks.
Methanol fuels as a substitute for gasoline as a motor vehicle fuel.

Table 3-6. Potential Emissions Reductions in 1998 Compared to 1985 Emissions From Source-Specific Control Strategies (Emissions in 1000 tons per year)[a]

	RACT	New CTG's	Federal Controls	Onboard	Stage II	Combined Stage II & Onboard	Fuel Volatility Control[b]	Enhanced I/M	New Highway Vehicle Emis. Stds	Methanol Fuels	ALL CONTROLS[c]
Nonattainment Cities by Design Value Category (in ppm O_3)											
0.13-0.14	120	17	62	51	69	72	140	67	20	0	480
0.15-0.17	260	27	120	90	110	130	230	94	34	0	860
0.18-0.26	82	5	39	29	35	42	59	29	11	11	270
> 0.26	24	6	30	20	0	28	0	25	9	9	130
Total (nonattain.)	490	55	250	190	220	270	430	210	73	20	1,700
Attainment Areas	0	0	230	200	0	200	710	0	99	0	1,200
TOTAL	490	55	480	390	220	480	1,100	210	170	20	3,000

[a] Totals are rounded.

[b] Estimates are equivalent annual reductions. Actual reductions are required only five months out of the year.

[c] "All Controls" include RACT, new CTG's, federal controls, combined Stage II and Onboard, gasoline volatility controls, enhanced I/M, and new mobile emission standards. Note that total reductions are slightly lower than the sum of each component category. This is because the reductions achieved by lowering gasoline volatility in combination with an enhanced I/M program, and a combining Stage II and Onboard program, are slightly lower than instituting each one alone.

Strategy Descriptions:

RACT = "Reasonable Available Control Technology" on all existing stationary sources that emit more than 25 tons per year of VOC.

New CTG's = new Control Technique Guidelines for existing stationary sources that emit more than 25 tons per year of VOC.

Federal Controls on selected small stationary sources of VOC (consumer and commercial solvents, and architectural surface coatings).

Onboard controls on motor vehicles to capture gasoline vapor during refueling.

Stage II control devices on gas pumps to capture gasoline vapor during motor vehicle refueling.

Fuel volatility controls which limit the rate of gasoline evaporation.

Enhanced inspection and maintenance (I/M) programs for cars and light-duty trucks.

New highway-vehicle emission standards for passenger cars and light-duty gasoline trucks.

Methanol fuels as a substitute for gasoline as a motor vehicle fuel.

Table 3-7. Potential Emissions Reductions in 2003 Compared to 1985 Emissions From Source-Specific Control Strategies
(Emissions in 1000 tons per year)[a]

	RACT	New CTG's	Federal Controls	Onboard	Stage II	Combined Stage II & Onboard	Fuel Volatility Control[b]	Enhanced I/M	New Highway Vehicle Emis. Stds	Methanol Fuels	ALL CONTROLS[c]
Nonattainment Cities by Design Value Category (in ppm O_3)											
0.13-0.14	130	17	64	74	77	80	140	69	28	0	510
0.15-0.17	280	27	120	130	130	140	230	97	49	0	920
0.18-0.26	86	5	41	44	40	48	62	30	16	11	290
> 0.26	27	6	32	30	0	32	0	26	13	9	150
Total (nonattain.)	520	56	260	280	240	300	440	220	110	21	1,900
Attainment Areas	0	0	240	310	0	310	750	0	150	0	1,400
TOTAL	520	56	500	580	240	610	1,200	220	250	21	3,300

[a] Totals are rounded.

[b] Estimates are equivalent annual reductions. Actual reductions are required only five months out of the year.

[c] "All Controls" include RACT, new CTG's, federal controls, combined Stage II and Onboard, gasoline volatility controls, enhanced I/M, and new mobile emission standards. Note that total reductions are slightly lower than the sum of each component category. This is because the reductions achieved by lowering gasoline volatility in combination with an enhanced I/M program, and a combining Stage II and Onboard program, are slightly lower than instituting each one alone.

Strategy Descriptions:

RACT = "Reasonable Available Control Technology" on all existing stationary sources that emit more than 25 tons per year of VOC.

New CTG's = new Control Technique Guidelines for existing stationary sources that emit more than 25 tons per year of VOC.

Federal Controls on selected small stationary sources of VOC (consumer and commercial solvents, and architectural surface coatings).

Onboard controls on motor vehicles to capture gasoline vapor during refueling.

Stage II control devices on gas pumps to capture gasoline vapor during motor vehicle refueling.

Fuel volatility controls which limit the rate of gasoline evaporation.

Enhanced inspection and maintenance (I/M) programs for cars and light-duty trucks.

New highway-vehicle emission standards for passenger cars and light-duty gasoline trucks.

Methanol fuels as a substitute for gasoline as a motor vehicle fuel.

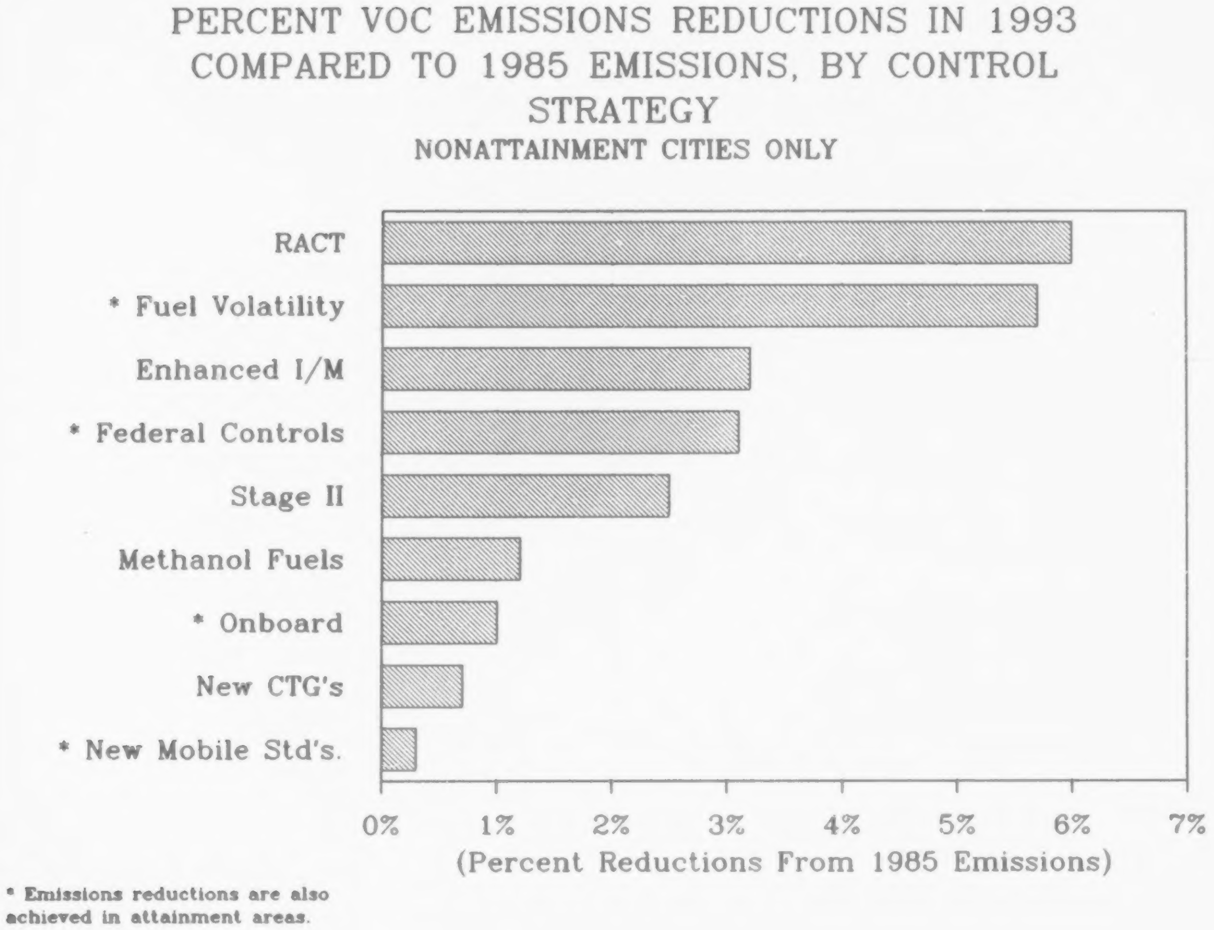


Figure 3-8. Percent Volatile Organic Compound (VOC) Emissions Reductions in 1993 Compared to 1985 Emissions, by Control Strategy

Strategy Descriptions

RACT = "Reasonably Available Control Technology" on all existing sources that emit more than 25 tons per year of VOC.

Fuel Volatility standards that limit the rate of gasoline evaporation.

Enhanced Inspection and Maintenance (I/M) programs for passenger cars and light-duty trucks.

Federal Controls on selected small stationary sources of VOC (consumer and commercial solvents, and architectural surface coatings).

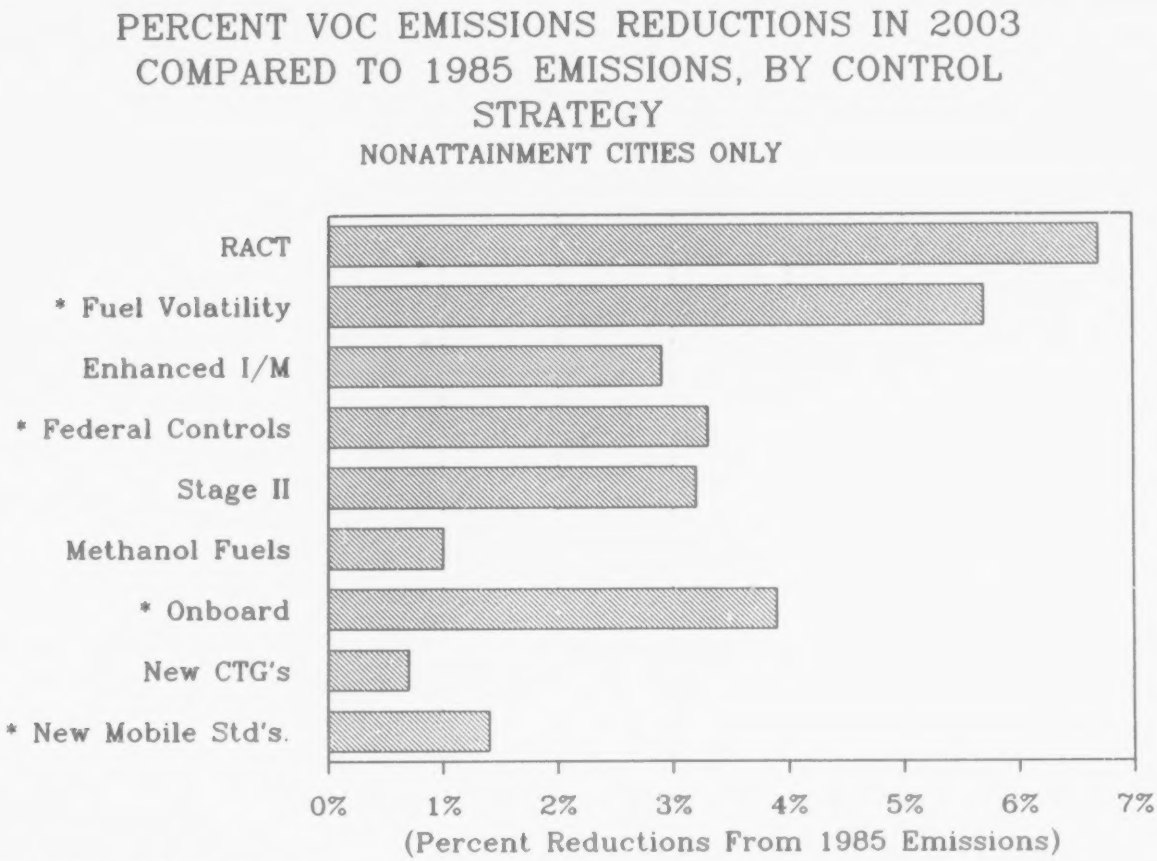
Stage II control devices on gas pumps to capture gasoline vapor during motor vehicle refueling.

Methanol Fuels as a substitute for gasoline as a motor vehicle fuel.

Onboard controls on motor vehicles to capture gasoline vapor during refueling.

New CTGs = new Control Technique Guidelines for existing stationary sources that emit more than 25 tons per year of VOC.

New Mobile Standards = more stringent tailpipe emission standards for passenger cars and light-duty gasoline trucks.



*** These control strategies will also create emissions reductions in attainment areas as well.**

Figure 3-9. Percent Volatile Organic Compound (VOC) Emissions Reductions in 2003 Compared to 1985 Emissions, by Control Strategy.

Strategy Descriptions

RACT = "Reasonably Available Control Technology" on all existing sources that emit more than 25 tons per year of VOC.

Fuel Volatility standards that limit the rate of gasoline evaporation.

Enhanced Inspection and Maintenance (I/M) programs for passenger cars and light-duty trucks.

Federal Controls on selected small stationary sources of VOC (consumer and commercial solvents, and architectural surface coatings).

Stage II control devices on gas pumps to capture gasoline vapor during motor vehicle refueling.

Methanol Fuels as a substitute for gasoline as a motor vehicle fuel.

Onboard controls on motor vehicles to capture gasoline vapor during refueling.

New CTGs = new Control Technique Guidelines for existing stationary sources that emit more than 25 tons per year of VOC.

New Mobile Standards = more stringent tailpipe emission standards for passenger cars and light-duty gasoline trucks.

categories in 1993 and 2003, except that the reductions from Onboard controls and new highway-vehicle standards increase because more of the older vehicles will have been replaced by newer ones equipped with additional controls. Table 3-8 presents a more detailed breakdown of percent emissions reductions in 1993. By 1993, total reductions average about 21 percent in nonattainment cities.

Figure 3-10 displays potential emissions reductions and the percentage of emissions that remain after all of the reductions have been accounted for. In 1993, after all controls are applied, emissions are approximately 70 percent of the 1985 total. Most of the remaining emissions are from small stationary sources that emit less than 25 tons of VOCs per year. As stated earlier, we are unable to identify controls for approximately one-quarter of the emissions inventory. About 80 percent of this one-quarter (or about 20 percent of the entire inventory) are emissions from small stationary sources.

The following subsections summarize the emissions reduction potential of each individual control strategy.

Reasonably Available Control Technology (RACT) on All Stationary Sources

The Clean Air Act requires that each State adopt, as part of its State Implementation Plan (SIP), "reasonably available control technology" (RACT) regulations for existing stationary sources of VOC in nonattainment cities. In our analysis, we have applied RACT-level controls on 39 stationary source categories including petroleum refining, certain types of chemical manufacturing, paper surface coating, automobile surface coating, gasoline terminals, service stations, and dry cleaning.

The source of our estimates of the percentage reduction in VOC emissions from RACT and of the data we used to calculate the cost of these controls, is a recent draft report prepared for EPA by Alliance Technologies Corporation[36]. EPA made available to us a series of memos detailing the methods used, technical references, and economic assumptions used by Alliance, from which our estimates are drawn. A complete list of our control cost assumptions, including control efficiencies and associated costs for each source type, is included in Appendix A.

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[36] William H. Battye, Mark G. Smith, and Mark Deese, Alliance Technologies Corporation, "Cost Assessment of Alternative National Ambient Air Quality Standards For Ozone, Draft Report," prepared for the U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Contract No. 68-02-4317, October 1987.

Table 3-8. Percent Emissions Reductions in 1993 Compared to 1985 Emissions From Source-Specific Control Strategies[a]

	RACT	New CTG's	Federal Controls	Onboard	Stage II	Combined Stage II & Onboard	Fuel Volatility Control[b]	Enhanced I/M	New Highway Vehicle Emis. Stds	Methanol Fuels	ALL CONTROLS[c]
Nonattainment Cities by Design Value Category (in ppm O_3)											
0.13-0.14	5	1	3	1	3	3	7	4	<1	0	21
0.15-0.17	7	1	3	1	3	3	7	3	<1	0	23
0.18-0.26	7	<1[d]	3	1	3	3	5	3	<1	1	22
> 0.26	3	1	4	1	0	3	0	4	<1	1	16
Total (nonattain.)	6	1	3	1	3	3	6	3	<1	1	21
Attainment Areas	0	0	2	1	0	1	6	0	<1	0	9

[a] Totals are rounded.

[b] Estimates are equivalent annual reductions. Actual reductions are required only five months out of the year.

[c] "All Controls" include RACT, new CTG's, federal controls, combined Stage II and Onboard, gasoline volatility controls, enhanced I/M, and new mobile emission standards. Note that total reductions are slightly lower than the sum of each component category. This is because the reductions achieved by lowering gasoline volatility in combination with an enhanced I/M program, and a combining Stage II and Onboard program, are slightly lower than instituting each one alone.

[d] "<1" means **less than** 1 percent.

Strategy Descriptions:

RACT = "Reasonable Available Control Technology" on all existing stationary sources that emit more than 25 tons per year of VOC.

New CTG's = new Control Technique Guidelines for existing stationary sources that emit more than 25 tons per year of VOC.

Federal Controls on selected small stationary sources of VOC (consumer and commercial solvents, and architectural surface coatings).

Onboard controls on motor vehicles to capture gasoline vapor during refueling.

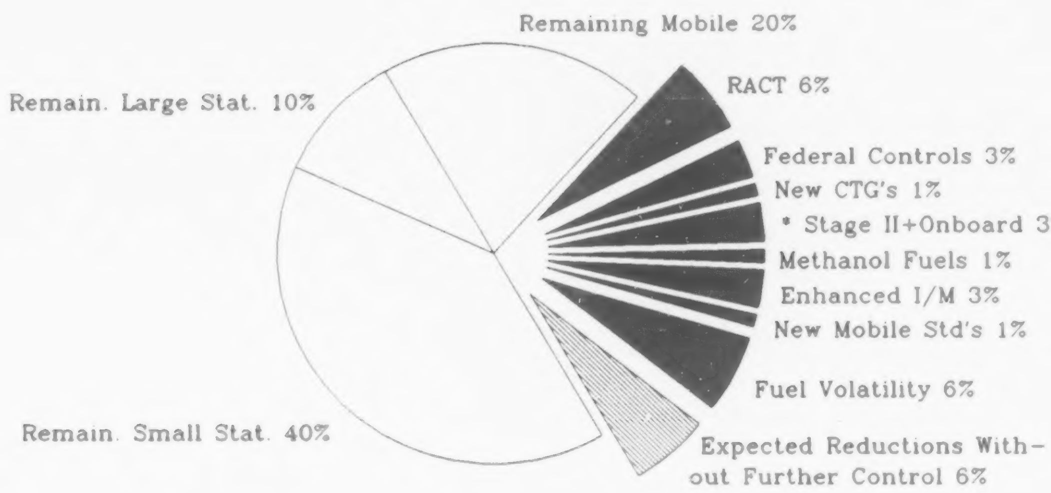
Stage II control devices on gas pumps to capture gasoline vapor during motor vehicle refueling.

Fuel volatility controls which limit the rate of gasoline evaporation.

Enhanced inspection and maintenance (I/M) programs for cars and light-duty trucks.

New highway-vehicle emission standards for passenger cars and light-duty gasoline trucks.

Methanol fuels as a substitute for gasoline as a motor vehicle fuel.



POTENTIAL VOC EMISSIONS REDUCTIONS AND REMAINING EMISSIONS IN 1993 AS A PERCENTAGE OF 1985 EMISSIONS

Nonattainment Cities Only

Notes:

* In a combined Stage II + Onboard control program, Stage II contributes about 70 percent of the reductions in 1993.

Figure 3-10. Potential Volatile Organic Compound (VOC) Emissions Reductions and Remaining Emissions in 1993 as a Percentage of 1985 Emissions in Nonattainment Cities

The pulled-out slices represent emissions that can be eliminated by each control strategy. The three connected slices represent emissions in 1993 that remain after all control strategies are applied. The category "Expected Reductions without Further Control" represents reductions achieved from existing State and EPA VOC regulations as of 1985. "Remaining Small Stationary" represents emissions from stationary sources that emit less than 25 tons per year of VOC.

Strategy Descriptions

RACT = "Reasonably Available Control Technology" on all existing sources that emit more than 25 tons per year of VOC.

Fuel Volatility standards that limit the rate of gasoline evaporation.

Enhanced Inspection and Maintenance (I/M) programs for passenger cars and light-duty trucks.

Federal Controls on selected small stationary sources of VOC (consumer and commercial solvents, and architectural surface coatings).

Stage II control devices on gas pumps to capture gasoline vapor during motor vehicle refueling.

Methanol Fuels as a substitute for gasoline as a motor vehicle fuel.

Onboard controls on motor vehicles to capture gasoline vapor during refueling.

New CTGs = new Control Technique Guidelines for existing stationary sources that emit more than 25 tons per year of VOC.

New Mobile Standards = more stringent tailpipe emission standards for passenger cars and light-duty gasoline trucks.

We estimate the emissions reductions achievable through RACT-level regulations by simulating controls on all existing stationary sources that emit more than 25 tons of VOCs per year;[37] in those cities that did not have an existing RACT regulation for a particular source category in their SIP as of 1985. For this analysis, additional RACT controls are applied only in nonattainment cities (although some bills also apply controls in selected attainment areas in States designated as ozone transport regions).

We estimate that applying RACT to all sources in nonattainment cities would lower VOC emissions by approximately 460 thousand tons per year in 1993, representing a six percent decline based on 1985 levels. Reductions continue to increase over time, with total reductions in nonattainment cities in 2003 estimated to be about 520 thousand tons per year, from 1985 levels.

Adoption of New "Control Technique Guidelines" (CTG's)

In the previous subsection, we analyzed the emissions reduction potential of applying all *currently* available RACT-level controls on all existing stationary VOC sources. Several additional stationary source categories are now being considered as candidates for development of new RACT regulations by EPA. These would be issued as "Control Technique Guidelines" (CTGs). Like the RACT controls analyzed in the previous section, nonattainment cities would be required to adopt these "new" RACT regulations on all *existing* stationary VOC sources that emit more than 25 tons of VOCs per year.

We are able to analyze the emission reduction potential from controls on (1) wood furniture coating, (2) autobody refinishing, (3) plastic parts coating, and (4) coke oven by-product plants. These four categories represent about one percent of the entire VOC inventory. Appendix A lists the control efficiency assumptions we used for these sources. We are unable to analyze the emissions reduction potential from other proposed new-CTG categories, and at least one of these--treatment, storage, and disposal facilities--might be quite large.

Emissions reductions from applying new CTG controls that we were able to analyze are estimated to be about 54 thousand tons per year in 1993, or about a one percent reduction based on 1985 emissions. This annual total is expected to increase by a few thousand tons in 2003.

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[37] Since a large fraction of small stationary sources (i.e., area sources) are reported as aggregate county-level totals in the 1985 NEDS emissions inventory, we have no way of knowing what fraction of those aggregate totals are contributed by individual sources greater than 25 tons per year. Therefore, for our analysis, we have assumed that one-third of the emissions from this aggregate total are from sources greater than 25 tons per year.

Federal Controls on Small VOC Sources

Many small sources of VOCs do not lend themselves to traditional forms of regulation (e.g., application of an add-on control device to reduce emissions). These sources individually emit small amounts of VOCs, but when aggregated over a region, they collectively contribute a significant portion of the VOC inventory. Such sources include consumer and commercial solvents, architectural surface coatings, agricultural pesticides, adhesives, and others.

Although several categories have been proposed as candidates for new federal controls in recent bills, we are only able to analyze commercial and consumer solvents, and architectural surface coatings. These two categories represent about nine percent of the entire emissions inventory. We believe, however, that emissions from these two categories represent most of the emissions that would fall under proposed federal controls.

EPA control efficiency estimates range between 23 percent[38] and 65 percent[39] for architectural surface coatings, and about 20 percent[40] for commercial and consumer solvents. For our analysis, we assume a 25 percent control efficiency for both categories. Since these would be federally-regulated, emissions reductions would occur nationwide (in nonattainment and attainment areas).

In 1993, federally-regulated controls on commercial and consumer solvents and on architectural surface coatings are estimated to reduce VOC emissions by 240 thousand tons per year in nonattainment cities, and about 220 thousand tons year in attainment areas. By 2003 in nonattainment cities, emissions reductions will reach about 260 thousand tons per year.

Controls on Gasoline Emissions From Vehicle Refueling

Gasoline vapors that escape from vehicle fuel tanks during refilling can be controlled by two fundamentally different methods. One method involves installation of a vapor recovery system on service station gasoline pumps, commonly referred to as "Stage II" vapor recovery. The other method relies on a control device installed on each vehicle as part of the emission control system (commonly referred to as "Onboard" controls). Stage II programs can become fully effective within a few years. The emissions reduction benefits of an Onboard control program gradually increase over time and achieve full potential after about 10 years, when most older, non-equipped vehicles have been replaced. In the following subsections, we describe the emissions reduction potential of each program individually, and in combination.

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[38] U.S. Environmental Protection Agency, Office of Air, Noise, and Radiation/Office of Air Quality Planning and Standards, "Control of Organic Emissions from Architectural Surface Coating," preliminary draft, March 1981, p. 3-11.

[39] U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, "Implications of Federal Implementation Plans (FIP's) for Post-1987 Ozone Nonattainment Areas," March 1987, p. V-78.

[40] Ibid., p. V-83.

"Onboard" refueling controls on motor vehicles

For this analysis, we assume that Onboard controls are required on all *new* gasoline vehicles starting in 1991 and that by 2003, *all* gasoline vehicles on the road will be equipped with Onboard controls due to fleet turnover. Assumptions regarding fleet turnover and control efficiencies are obtained from EPA's recent gas-marketing regulatory impact analysis.[41] [42] Because these controls apply to all new gasoline vehicles, emissions reductions will occur nationwide (in both nonattainment and attainment areas).

We estimate that in 1993, Onboard controls will eliminate about 81 thousand tons per year of VOC emissions in nonattainment cities, and 170 thousand tons per year nationwide, representing about a one percent reduction, compared to 1985 emissions. In 2003, total nationwide VOC reductions increase to about 580 thousand tons per year, or about a three percent reduction based on 1985 levels. These results reflect only Onboard controls for vehicle refueling and do not include reductions from additional Stage II controls. An analysis of a combined Onboard and Stage II vapor recovery program is presented later.

"Stage II" refueling vapor recovery

Unlike Onboard controls, which are applied nationwide, we assume Stage II controls are only installed in nonattainment cities. Congressional proposals have generally limited the Stage II requirement to these areas. Emissions reductions in 1993 and 2003 are estimated to be about 190 thousand and 240 thousand tons per year, respectively, which amounts to about a three percent reduction in both 1993 and 2003, relative to 1985 emissions. We assume a control efficiency of 86 percent, which represents EPA's average estimate for a Stage II program with annual enforcement. Note that the percent emissions reductions ultimately achievable with Stage II and Onboard controls are roughly comparable. However, in 1993, Onboard is less effective than Stage II, because fleet turnover will have only just begun.

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[41] U.S. Environmental Protection Agency, Office of Air and Radiation, "Draft Regulatory Impact Analysis: Proposed Refueling Emission Regulations for Gasoline-Fueled Motor Vehicles--Volume I, Analysis of Gasoline Marketing Regulatory Strategies," EPA-450/3-87-001a, July 1987, p. 2-33, 3-18.

[42] We assume that the percent reduction in refueling emissions from use of Onboard controls, as derived from EPA's gas marketing analysis (Ibid., p. 3-18), is 28 percent, 58 percent, and 76 percent in 1993, 1998, and 2003, respectively.

Combined Stage II and Onboard controls

If both Stage II and Onboard controls are adopted, the percent emissions reductions in nonattainment cities in 1993 and 2003 are estimated to be about three and four percent, respectively, relative to 1985 emissions. As the reduction benefits from Onboard controls increase through time (due to fleet turnover), the benefits from the combined strategy is only slightly greater than either method above. We assume a combined control efficiency of about 83 percent based on EPA-derived data.[43]

Enhanced Motor Vehicle Inspection and Maintenance (I/M) Programs

For this analysis, we define an enhanced motor vehicle inspection and maintenance (I/M) program as one including all requirements of the existing California I/M program (among the most stringent in the nation), plus the following improvements: annual testing for all pollutants (VOC, NO_x, carbon monoxide, and particulates) on all vehicles, improved visual inspection of the emissions control system to detect tampering and other functional defects, and a repair cost ceiling of $200 per year. We have assumed that enhanced I/M programs are instituted in all nonattainment areas. Recent bills also require I/M in selected attainment cities within States designated as ozone transport regions. However, since the selection of attainment cities differs between these proposals, we have chosen to limit our analysis to nonattainment cities.

For cities without an existing I/M program as of 1987, the full emission reduction benefit of an enhanced I/M program is applied. If a city already had an I/M program as of 1987, then an incremental emission reduction benefit, representing the reductions achieved by going from an existing to an enhanced program, is applied. Emissions reduction benefit assumptions are taken from Sierra Research, Inc. (1988).[44] We assume that the VOC emission reduction potential of existing I/M programs is about 12 percent. The full benefit of enhanced programs is about 30 percent, while the incremental benefit gained by switching from an existing to an enhanced program is about 17 percent.

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[43] U.S. Environmental Protection Agency, op. cit., footnote 41, p. 3-18.

[44] Sierra Research, Inc., "The Feasibility and Costs of More Stringent Mobile Source Emission Controls," contractor report prepared for the Office of Technology Assessment, January 20, 1988. p. 9-23.

We estimate that enhanced I/M programs in nonattainment cities will reduce VOC emissions by about 250 thousand tons per year in 1993 and by 220 thousand tons per year in 2003.[45] This represents about a three percent reduction in both 1993 and 2003, based on 1985 emissions. Enhanced I/M programs become slightly less effective over time because a larger percentage of the vehicle fleet will be newer, lower-emitting vehicles.

More Stringent Highway-Vehicle Emission Standards

This analysis includes the VOC emissions reduction potential of instituting more stringent tailpipe controls on new passenger cars and light-duty gasoline-fueled trucks. The standards we analyzed were determined to be the most stringent technologically feasible, given currently "available" control technology, according to Sierra Research (1988).[46] [47] Sierra Research assumes that these standards can be met after 50,000 miles of *controlled test* driving for passenger cars, and 120,000 miles for light-duty trucks; however, VOC emission rates after 50,000 miles (for cars) and 120,000 miles (for trucks) of *actual* use by vehicle owners would likely exceed these standards. We assume that new standards go into effect in 1990 for passenger cars, and 1992 for light-duty trucks.

We estimate that new highway vehicle standards reduce VOC emissions by less than one percent nationwide, in 1993. By 2003, reductions increase to just over one percent nationwide, compared to 1985 emissions. The increase in emissions reductions during this period is due to the gradual replacement of older vehicles with newer, cleaner ones.

Limits on Fuel Volatility

Lowering gasoline volatility (i.e., lowering the rate of evaporation) reduces emissions during refueling at the gas pump and during refilling of underground gasoline storage tanks, and reduces evaporative emissions from vehicle fuel systems. For this analysis, we assume that fuel volatility is reduced to nine pounds per square inch during the five-month summertime period when most ozone concentrations most often exceed the standard.

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[45] Nitrogen oxides, carbon monoxide, and particulate emissions reduction benefits are also gained by I/M programs, but are not calculated in this analysis.

[46] Sierra Research, Inc., op. cit., footnote 44, p. 1-3.

[47] The new emission standards used in our analysis are as follows:
(in "grams of pollutant emitted per mile travelled", g/mile)
Passenger cars -- VOC: 0.25 g/mile; NO_x: 0.4 g/mile
Light-duty gasoline trucks (by truck weight) --
  (less than 3,750 pounds) VOC: 0.34 g/mile; NO_x: 0.46 g/mile
  (3,751 to 6,000 pounds) VOC: 0.43 g/mile; NO_x: 0.80 g/mile
  (6,000 to 8,500 pounds) VOC: 0.55 g/mile; NO_x: 1.15 g/mile

However, for purposes of comparing total annual emissions reductions, we have scaled up the annual emissions reductions as though the volatility limits would be in effect year-round. Data for the analysis comes from EPA[48].

We estimate that limiting gasoline volatility would lower VOC emissions by about six percent in both nonattainment and attainment areas in 1993. Actual emissions reductions, in 1993, are estimated to be about 1.2 million tons per year, nationwide, of which about 440 thousand tons per year are achieved in nonattainment cities (actual VOC emissions reductions would be about 500 thousand tons nationwide, and 180 thousand tons in nonattainment areas, during the five-month ozone season). Total reductions stay relatively constant between 1993 and 2003.

Alternative Motor Vehicle Fuels: Methanol

H.R.3054 and S.1894 both mandate the use of "alternative" motor vehicle fuels for some ozone nonattainment areas. The "alternative" fuel which is most commonly considered for reducing ozone is methanol (either 100 percent or "neat" methanol, or a blend of at least 85 percent methanol and up to 15 percent gasoline). Current U.S. production of methanol totals about one billion gallons per year, mostly from natural gas. About 300 million gallons are currently used in oxygenated fuel blends.[49]

Methanol is a VOC that reacts more slowly in the atmosphere and consequently produces less ozone than VOCs emitted from combustion and evaporation of gasoline. Per mile travelled, substituting methanol for gasoline as motor vehicle fuel is roughly estimated to be between 30 to 90 percent as effective in reducing ozone concentrations as completely eliminating the emissions from the gasoline-fueled vehicles.[50] Based on these estimates, substituting methanol for gasoline for 10 percent of the vehicle miles travelled (VMT) in an area would yield the same ozone benefits as simply reducing VMT by three to nine percent. The relative ozone-producing potential of gasoline and methanol-fueled vehicles depends on assumptions about the volatility limits imposed for gasoline, exhaust and evaporative emissions limits imposed on both gasoline and methanol-fueled vehicles (including limits on total VOCs, methanol, and formaldehyde -- a relatively reactive product of methanol combustion as well as gasoline combustion), and how vehicle design is optimized for methanol use.

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[48] U.S. Environmental Protection Agency, Office of Air and Radiation, Office of Mobile Sources, "Draft Regulatory Impact Analysis: Control of Gasoline Volatility and Evaporative Hydrocarbon Emissions from Motor Vehicles," July 1987.

[49] "Oxygenated fuel blends" refers to gasoline to which either ethanol (grain alcohol), methanol plus ethanol, or methyl tertiary butyl ether (MTBE), a methanol derivative, has been added, resulting in a mixture which is about 90 percent gasoline by volume. S.1894 and H.R.3054 mandate the use of oxygenated fuel blends during the colder months of the year in carbon monoxide nonattainment areas.

[50] U.S. Environmental Protection Agency, "Guidance on Estimating Motor Vehicle Emission Reductions from the Use of Alternative Fuels and Fuel Blends," EPA report number EPA-AA-TSS-PA-87-4, Research Triangle Park, NC, January 1988.

Methanol substitution: centrally-owned fleets

S.1894 and H.R.3054 both include provisions for use of alternatively fueled vehicles in centrally owned vehicle fleets. In 1986, six million cars and two million light trucks in centrally owned fleets of 10 or more vehicles accounted for an estimated 15 percent of VMT nationwide.[51] For our analysis, we assume that all centrally owned fleets of 10 or more light duty vehicles in areas with design values of 0.18 ppm or higher will be required to operate strictly on neat methanol by 1993.[52] Further assuming that on a per mile basis, substituting methanol for gasoline is equivalent to reducing VOC emissions by half, a year-round requirement that methanol be substituted for gasoline would result in total VOC reductions in areas with design values of 0.18 ppm or higher of about 22,000 tons. Compared to 1985 VOC emissions, this is an average reduction of about 1.2 percent in each area.

3.4 Comparison of Potential Emissions Reductions and Reductions Needed to Attain the Ozone Standard

Without Additional Controls

Figure 3-11 shows variability among nonattainment cities in the changes in VOC emissions predicted to occur between 1985 and 1993, assuming that nothing is added to existing State and EPA regulations. For each city, at its design value, we have graphed the percentage change in emissions from the 1985 baseline expected to occur due to the regulations included in State Implementation Plans (SIP) as of 1985, the current Federal Motor Vehicle Control Program, and population and economic growth.

We have graphed cities by design value because it is a reasonable predictor of the emissions reductions needed to reach the standard. The graph also displays estimates of the reductions needed to reach the 0.12-ppm ozone standard, as a function of design value. The two curves arching across the graph represent high and low estimates of the percentage reduction in emissions that cities falling within a given design value range need attain the

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[51] Automotive Fleet 1987 Fact Book, Volume 26 Supplement, p.9, Bobit Publishing Co., 1987. Centrally owned fleet vehicles account for such a large fraction of VMT because each fleet vehicle is driven over two-and-a-half times as many miles in a year as is averaged by the general vehicle population.

[52] Centrally-owned fleets turn over in about three years (the total vehicle population takes more than ten years to turn over), so we assume that fleet conversion would begin with all new vehicles registered in fleets in 1991.

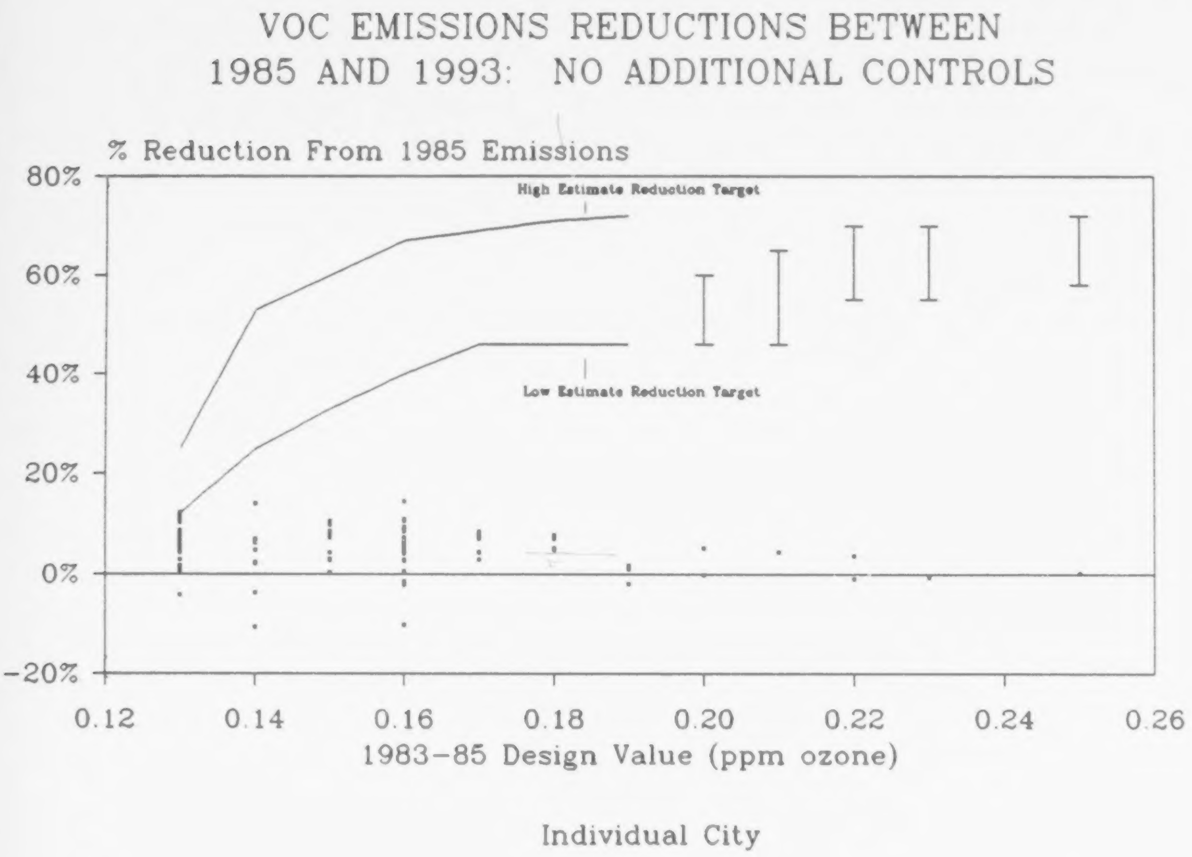

Figure 3-11. Volatile Organic Compound (VOC) Emissions Reductions Between 1985 and 1993, Assuming No Change from 1985 VOC Regulations.

Each square represents a nonattainment city. The location on the graph shows the VOC emissions reductions (as a percentage of 1985 levels) by 1993 given the State and EPA VOC regulations in place in 1985. Cities below the "0%" line experience a net increase in emissions between 1985 and 1993. The horizontal axis shows the "design value", a measure of peak ozone concentration used to determine the emissions reductions needed to attain the ozone standard. The two curves arching across the graph and vertical bars to the right of the curves show the upper and lower bounds of VOC reductions needed to attain the standard. The vertical bars show estimated control requirements explicitly for major urban areas with area-wide design values greater than 0.19 ppm.

standard. The area between these two curves represents a range of uncertainty in our estimates of required emissions reductions. The five vertical bars to the right of the two curves represent estimates of emissions reduction requirements for individual cities with design values above 0.19 ppm. Areas with design values above 0.19 ppm have been excluded from the graph because they are thought to be impacted significantly by transport from large cities upwind. We have also omitted three cities with design values greater than 0.26 ppm (all three are in southern California).

Summarizing how to read Figure 3-11, the *squares* show the change in VOC emission in each nonattainment city *projected* for 1993 (assuming existing regulations) and the curves and vertical bars show the upper and lower bounds of the change *needed*, in each city, to attain the ozone standard by 1993.

As Figure 3-11 illustrates, the change in VOC emissions that would occur by 1993 without further control ranges from an increase of about 10 percent to a reduction of about 15 percent. Emissions in most cities are expected to decline, due to the replacement of today's cars with lower- emitting new cars. However, emissions may increase in some cities that are expected to experience high population growth.

Note that without additional controls only a few cities with design values of 0.13 ppm may be able to attain the ozone standard by 1993. Most nonattainment areas will not be much closer to meeting the standard than they are today.

With Additional Fuel Volatility Limitations and Onboard Controls

In the previous subsection, we analyzed the emissions reductions which would be expected in 1993 if only State and federal regulations existing in 1985 were to be applied; these estimates represent a "no-further-control" scenario from which we can gauge the effectiveness of additional control measures. Recently, EPA announced proposals requiring limits on fuel volatility[53] and Onboard controls on new motor vehicles[54]. Because these controls could become law in the near future, their exclusion from a baseline "no-further-control" scenario in a future year may not be appropriate. Therefore, the purpose of this subsection is to show how the addition of these two control strategies would affect future emissions reductions if they were added to the "no-further-control" baseline scenario.

Figures 3-12 and 3-13 illustrate the percent reductions which would be achieved in 1993 and 2003, respectively, from existing regulations plus fuel volatility and Onboard controls (assuming these regulations are adopted in the near future). On average, in 1993,

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[53] 52 *Federal Register* 31274 (Aug. 19, 1987)
[54] Ibid., p. 31162.

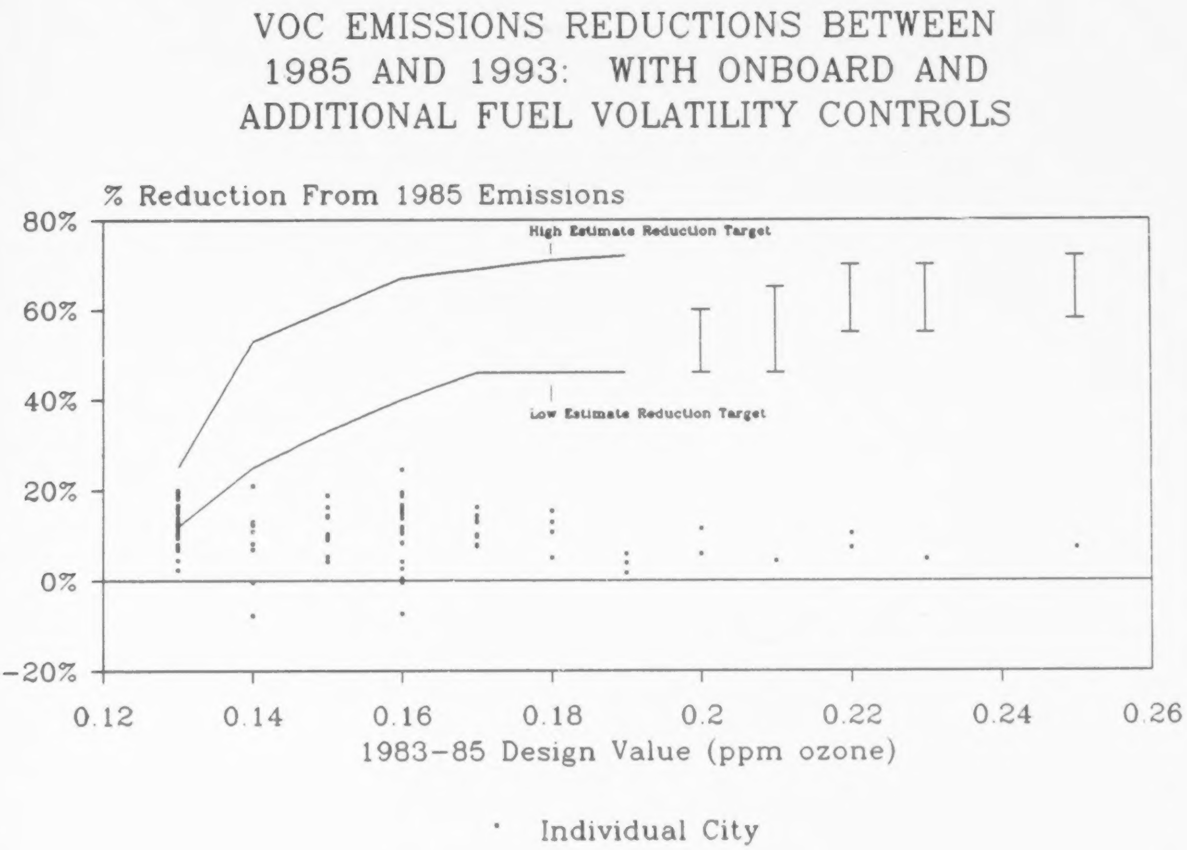

Figure 3-12. Volatile Organic Compound (VOC) Emissions Reductions Between 1985 and 1993, Including Onboard and Additional Fuel Volatility Controls.

Each square represents a nonattainment city. The location on the graph shows the projected VOC emissions reductions (as a percentage of 1985 levels) that each city can achieve by 1993 if Onboard technology (to control motor vehicle gasoline refueling emissions) and fuel volatility limits are adopted in addition to the State and EPA VOC regulations in place in 1985. Cities below the "0%" line experience a net increase in emissions between 1985 and 1993. The horizontal axis shows the "design value", a measure of peak ozone concentration used to determine the emissions reductions needed to attain the ozone standard. The two curves arching across the graph and vertical bars to the right of the curves show the upper and lower bounds of VOC reductions needed to attain the standard. The vertical bars show estimated control requirements explicitly for major urban areas with area-wide design values greater than 0.19 ppm.

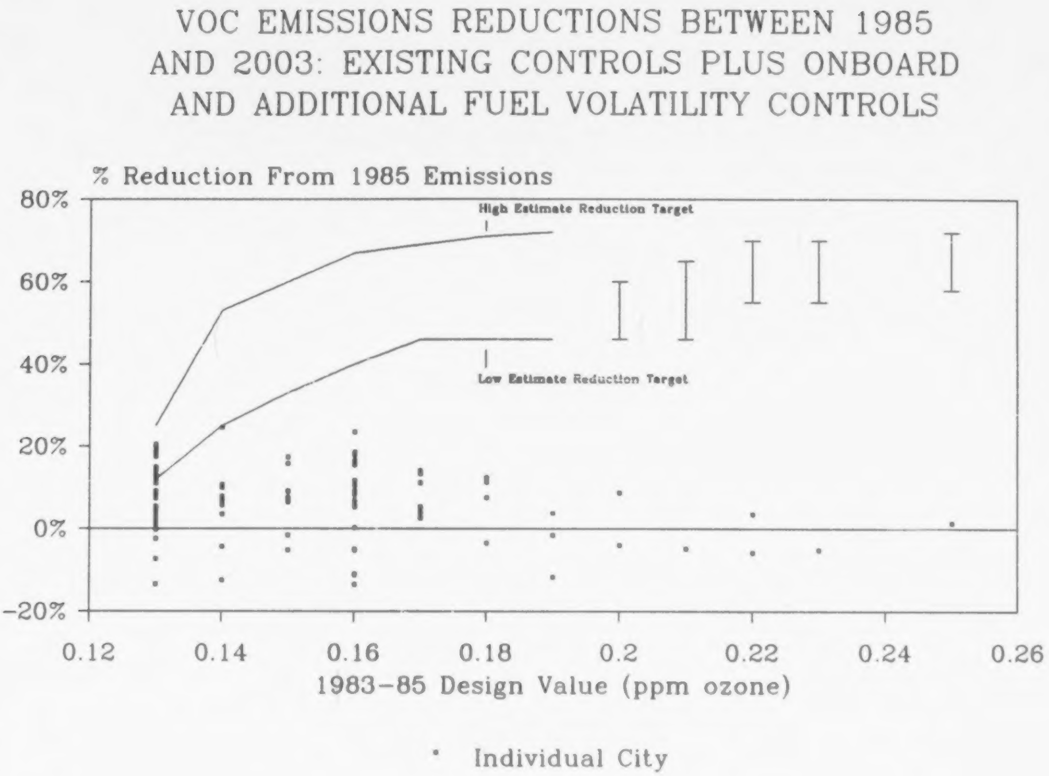

Figure 3-13. Volatile Organic Compound (VOC) Emissions Reductions Between 1985 and 2003, Including Onboard and Additional Fuel Volatility Controls.

Each square represents a nonattainment city. The location on the graph shows the projected VOC emissions reductions (as a percentage of 1985 levels) that each city can achieve by 2003 if Onboard technology (to control motor vehicle gasoline refueling emissions) and fuel volatility limits are adopted in addition to the State and EPA VOC regulations in place in 1985. Cities below the "0%" line experience a net increase in emissions between 1985 and 2003. The horizontal axis shows the "design value", a measure of peak ozone concentration used to determine the emissions reductions needed to attain the ozone standard. The two curves arching across the graph and vertical bars to the right of the curves show the upper and lower bounds of VOC reductions needed to attain the standard. The vertical bars show estimated control requirements explicitly for major urban areas with area-wide design values greater than 0.19 ppm.

fuel volatility limits will lower emissions by about an additional six percent below 1985 levels; Onboard controls have only a minor effect in 1993 due to the small numbers of Onboard-equipped vehicles which would be on the road. As illustrated in Figure 3-12, when these control measures are added the percent reductions in many cities with design values of 0.13 ppm fall between the two curves. These cities may be able to attain the ozone standard in 1993. By 2003, most cars and trucks will be equipped with Onboard controls. Even so, Figure 3-13 shows that in 2003, the picture does not substantially improve compared to 1993, primarily because of the influence of additional emissions due to population and economic growth. Fuel volatility and Onboard controls, alone, are not expected to offset new emissions growth in 2003.

With All Control Strategies Analyzed by OTA

Figure 3-14 illustrates the percent reduction in VOC emissions that could be achieved by requiring all the control strategies listed in the beginning of this section. Emissions in 1993 would be lowered between about two and 40 percent, depending on the city. Figure 3-15 shows that emissions reductions do not substantially change between 1993 and 2003. This "flat" trend between 1993 and 2003 is due to the competing influences of population growth (which drives new emissions growth) and the effects of additional emissions control programs. The emissions reduction benefits from these programs act to cancel out new emissions growth due to rising populations.

For some cities, the VOC emissions reductions from all controls may be more than needed to attain the ozone standard. For other nonattainment cities with slightly higher design values, the reductions projected for 1993 fall within the range of reductions which might be needed. For most cities, however, projected reductions fall considerably below the amount needed to meet the standard. The issues of excess, or overcontrol, and reduction shortfalls (undercontrol) are discussed in the next subsection.

As stated earlier, the emissions reductions reported here represent control methods that we know can be applied in the near term. We are able to analyze the emissions reduction potential for about three-quarters of the VOC emissions inventory. The remaining one-quarter represents mostly emissions from stationary sources for which we either could not find applicable control methods or that we could not analyze because of a lack of suitable information.

Estimates of Possible Excesses and Shortfalls in Emissions Reductions Required to Attain the Ozone Standard

In this section we estimate: 1) the extent of *overcontrol* in nonattainment cities with the lowest design values, and 2) the *shortfall* in nonattainment cities with higher design values, expected to occur after applying all of the VOC controls discussed earlier. Table 3-9

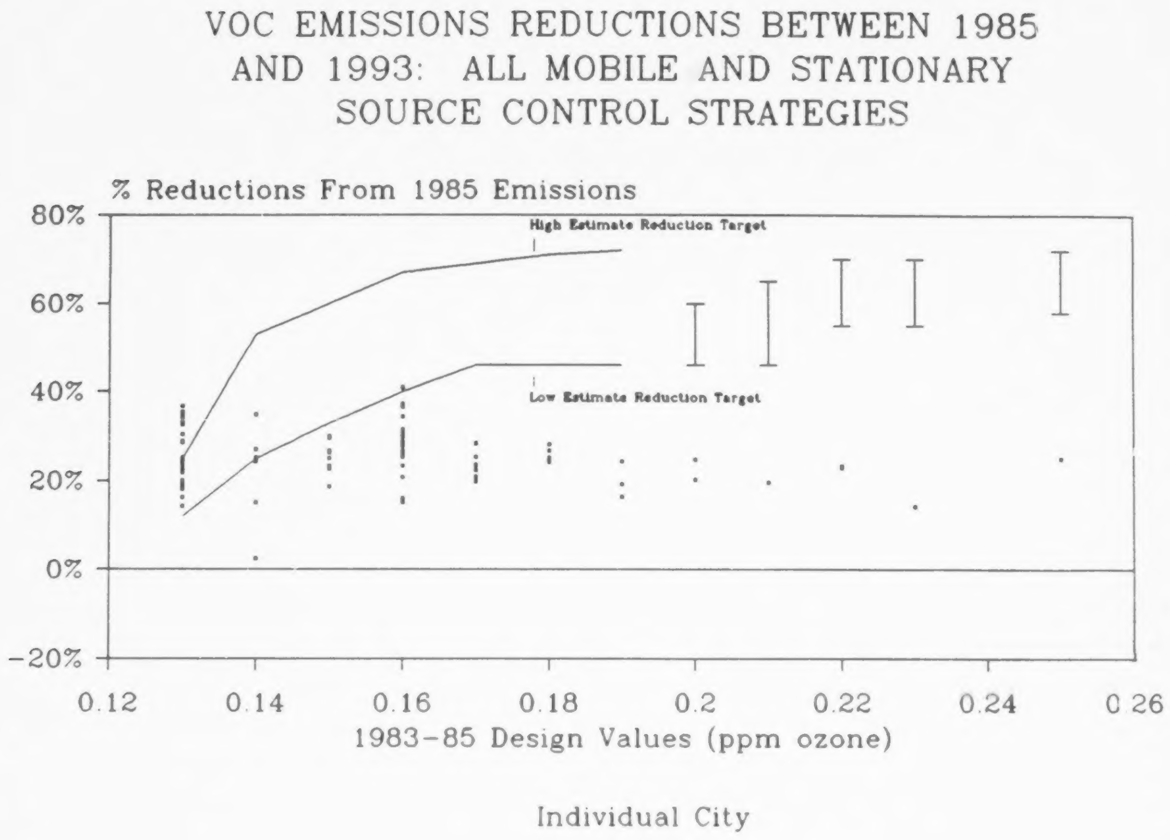

Figure 3-14. Volatile Organic Compound (VOC) Emissions Reductions Between 1985 and 1993, Including All Mobile and Stationary Source Control Strategies.

Each square represents a nonattainment city. The location on the graph shows the projected VOC emissions reductions (as a percentage of 1985 levels) that each city can achieve by 1993 if all additional mobile and stationary source control strategies we analyzed are adopted in addition to the State and EPA VOC regulations in place in 1985. The horizontal axis shows the "design value", a measure of peak ozone concentration used to determine the emissions reductions needed to attain the ozone standard. The two curves arching across the graph and vertical bars to the right of the curves show the upper and lower bounds of VOC reductions needed to attain the standard. The vertical bars show estimated control requirements explicitly for major urban areas with area-wide design values greater than 0.19 ppm.

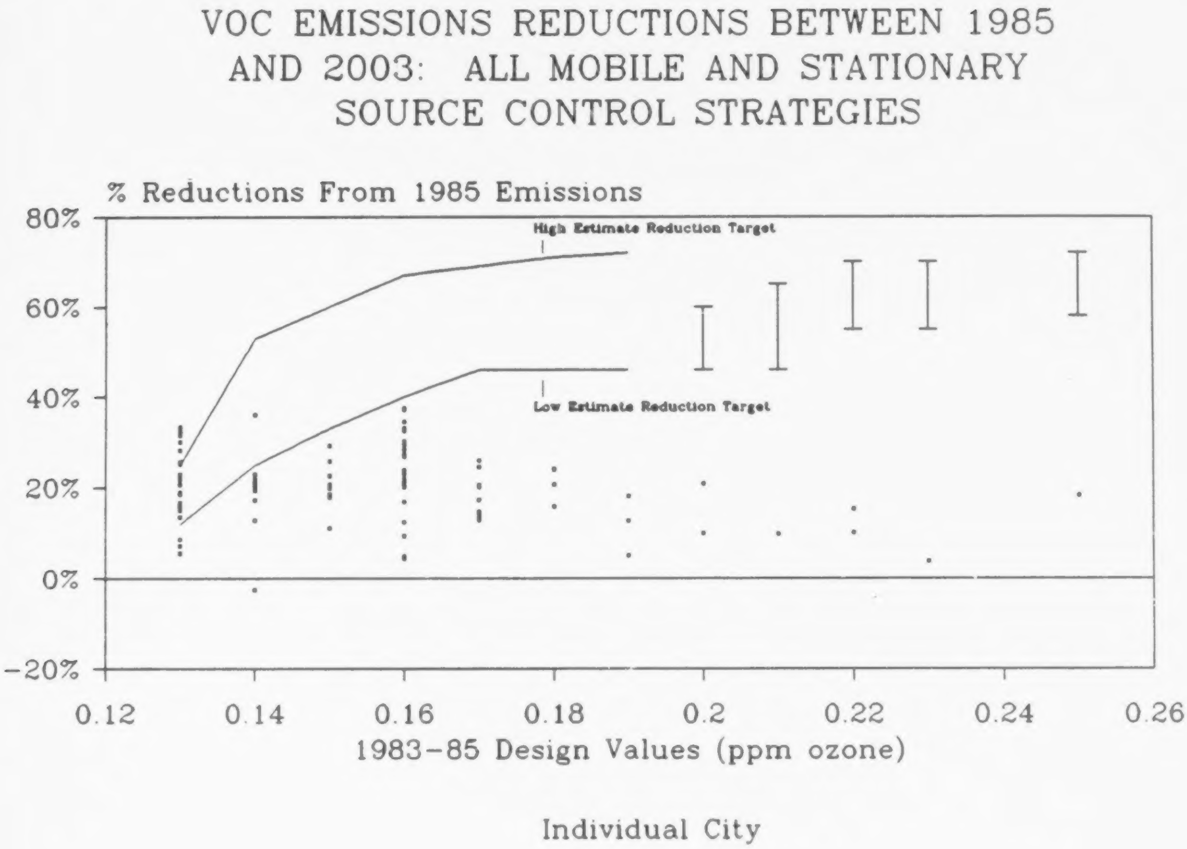

Figure 3-15. Volatile Organic Compound (VOC) Emissions Reductions Between 1985 and 2003, Including All Mobile and Stationary Source Control Strategies.

Each square represents a nonattainment city. The location on the graph shows the projected VOC emissions reductions (as a percentage of 1985 levels) that each city can achieve by 2003 if all additional mobile and stationary source control strategies we analyzed are adopted in addition to the State and EPA VOC regulations in place in 1985. The horizontal axis shows the "design value", a measure of peak ozone concentration used to determine the emissions reductions needed to attain the ozone standard. The two curves arching across the graph and vertical bars to the right of the curves show the upper and lower bounds of VOC reductions needed to attain the standard. The vertical bars show estimated control requirements explicitly for major urban areas with area-wide design values greater than 0.19 ppm.

Table 3-9. Estimates of Possible Overcontrol Resulting From All VOC Control Strategies, in 1993

Nonattainment Cities by Design Value Category (ppm O_3)	1985 Emissions (1000 tons/year)	Possible Overcontrol[a]			
		1000 Tons/Year		% of 1985 Emissions	
		Best Estimate	Range	Best Estimate	Range
0.13-0.14	2,200	99	1-290	4	0-13
0.15-0.17	3,600	0	0-1	0	0
0.18-0.26	1,100	0	-	0	-
> 0.26	770	0	-	0	-
Totals	7,700	99	1-290	1.3	0-3.7

[a] *Possible overcontrol* represents the VOC emissions reductions in excess of the total reductions needed to attain the ozone standard.

displays estimates of overcontrol from all VOC control strategies in 1993. We present a "best estimate" as well as an uncertainty range for the four design value categories. To obtain these estimates, we calculate the reductions in VOC emissions required to reach the ozone standard in each city, assuming both VOC- and NO_x-rich conditions. (An earlier subsection explains how the particular mix of pollutants in a city affects the reductions required to meet the standard.) Because we do not have data on the pollutant mix in each city, we feel it is important to present a range of uncertainty, in addition to the estimate one would expect if all cities had the nationwide average mix of VOCs and NO_x.

Our best estimate is that adoption of all controls might over control VOC emissions in low design-value nonattainment cities by about 100 thousand tons per year, or about four percent of their 1985 emissions. The overcontrol possible in these cities ranges from zero to 290 thousand tons per year.

VOC reductions in attainment areas are a potentially significant source of overcontrol in the sense that these areas do not need to reduce their emissions any further to meet the ozone standard locally. We know that there will be *some* benefit to nonattainment cities from controls in attainment areas, especially those in ozone transport regions, but we are not able to estimate how much. Moreover, even in cities that already meet the standard, lowering ozone concentrations even further will provide some benefit. Both S.1894 and H.R.3054 explicitly mandate VOC controls in attainment areas in regions of the country where transport of ozone and its precursors is a problem. Under S.1894, for example, VOC emissions reductions in attainment areas in ozone transport regions could be about 570 thousand tons per year in 1993 (about a 16 percent decrease based on 1985 emissions) after adoption of all applicable controls.[55] The total emissions reduction in all attainment areas from application of the nationwide control measures discussed above is about one million tons of VOCs per year, in 1993, or about nine percent, based on 1985 emissions. These reductions result from controls on small VOC sources, limits on fuel volatility, Onboard controls, and more stringent tailpipe standards for highway vehicles.

Table 3-10 presents our estimates of the additional VOC emissions reductions nonattainment cities must achieve to attain the ozone standard after all controls have been applied. Calculation procedures are similar to those discussed above. Our best estimate is

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[55] We assume that all VOC control strategies listed earlier, except Stage II and new CTG's, also apply in attainment areas in regions of the country where ozone transport is a problem. Of the 570 thousand tons per year of VOC reductions, about 270 thousand tons are from RACT and enhanced I/M programs; 300 thousand tons are from federal controls, fuel volatility limits, and Onboard more stringent highway vehicle standards.

Table 3-10. Estimates of Possible Undercontrol Resulting From All VOC Control Strategies, in 1993

Nonattainment Cities by Design Value Category (ppm O_3)	1985 Emissions (1000 tons/year)	Possible Undercontrol[a] [b]			
		1000 Tons/Year		% of 1985 Emissions	
		Best Estimate	Range	Best Estimate	Range
0.13-0.14	2,200	89	10-260	4	0-12
0.15-0.17	3,600	940	470-1,400	26	13-39
0.18-0.26	1,100	410	290-520	36	26-46
> 0.26	770	490	460-540	64	60-70
Totals	7,700	1,900	1,200-2,700	25	16-35

[a] *Possible undercontrol* represents the extra emissions reductions cities would need to attain the ozone standard.

[b] Emissions reductions from use of methanol as a motor vehicle fuel are not included in this analysis. Inclusion of this strategy in cities with design values greater than, or equal to, 0.18 ppm would decrease undercontrol (i.e., increase emissions reductions) by about one percent.

that the shortfall of emissions reductions will be about 1.9 million tons per year in 1993, or about 25 percent of 1985 emissions in these areas.[56] The shortfall in 1993 could be as low as 1.2 million or as high as 2.7 million tons per year.

3.5 Costs of Control Strategies Analyzed by OTA

This section summarizes the costs of the control strategies analyzed by OTA. Because we are unable to analyze the cost of *additional* emission controls required to make up the shortfall discussed above, we are not able to estimate the total costs of actually attaining the standard.

We estimate that the total cost of all controls analyzed by OTA in nonattainment cities will be about $5.8 billion to $6.8 billion per year, in 1993. By 2003, costs will increase to about $7.7 billion to $8.9 billion per year in nonattainment cities, primarily because of the higher percentage of highway vehicles with more stringent controls. Table 3-11 displays the costs in 1993, 1998, and 2003 by source category. Figure 3-16 displays the ranges of costs in nonattainment cities in 1993 and 2003.

Table 3-12 presents the "cost-effectiveness" (the cost per ton of VOC eliminated) of specific control measures for the three forecast years. Figure 3-17 illustrates the cost-effectiveness of control measures in nonattainment cities in 1993. The solid bars represent the average cost-effectiveness in all nonattainment cities. Uncertainty in the cost effectiveness estimates is denoted by the thin horizontal lines. Note the wide range in average cost-effectiveness across control measures, from about $500 per ton for limits on fuel volatility to about $39,000 per ton for methanol fuels.

We also analyzed the cost and emissions reduction impacts of limiting the application of controls on individual sources to those where the cost-effectiveness is equal to, or less than, $5,000 per ton of VOCs reduced. We estimate that in 1993, by not requiring controls that would cost more than $5,000 per ton, total costs in nonattainment cities would drop about $1.6 billion per year, lowering total costs by about 26 to 31 percent. About 200 thousand tons per year of VOC emissions reductions would be lost in nonattainment cities, lowering total reductions by about 12 percent. The declines occur entirely in the "RACT-on-all-sources" and "New-CTGs" categories.

A brief discussion of the costs and cost-effectiveness of each of the control strategies, including the data sources from which the estimates are calculated, follows.

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[56] It is interesting to note that the magnitude of this shortfall (25 percent) is roughly equivalent to the portion of the inventory that we are unable to analyze.

Table 3-11. Estimated Costs of Selected Control Strategies Analyzed by OTA
(costs in million dollars per year)[a]

	1993			1998			2003		
	Nonattainment Cities	Attainment Areas	Total	Nonattainment Cities	Attainment Areas	Total	Nonattainment Cities	Attainment Areas	Total
RACT	1,600	--[b]	1,600	1,700	--	1,700	1,900	--	1,900
New CTGs	300	--	300	310	--	310	320	--	320
Federal Controls	420	390	810	440	400	840	460	420	880
Onboard	90	97	190	240	250	490	350	350	720
Stage II	190	--	190	220	--	220	240	--	240
Enhanced I/M (low)[c]	2,500	--	2,500	2,800	--	2,800	3,100	--	3,100
Fuel Volatility (low)[d]	84	150	240	91	150	240	93	160	250
New Highway Vehicle Standards[e]	250	330	580	680	920	1,600	980	1,300	2,300
Methanol Fuels	860	--	860	770	--	770	810	--	810
TOTAL (low estimate)	5,800	910	6,800	6,800	1,700	8,400	7,700	2,200	10,000
TOTAL (high estimate)	6,800	1,000	7,800	7,800	1,800	9,600	8,900	2,300	11,000

[a] Totals are rounded.

[b] "--" means control strategy applied only in nonattainment cities.

[c] Includes costs of VOC, NO_x, and carbon monoxide control.

[d] Estimates are equivalent annual costs. Controls required only five months out of the year.

[e] Includes costs of both VOC and NO_x control.

Strategy Descriptions

RACT = "Reasonable Available Control Technology" on all existing stationary sources that emit more than 25 tons per year of VOC.

New CTG's = new Control Technique Guidelines for existing stationary sources that emit more than 25 tons per year of VOC.

Federal Controls on selected small stationary sources of VOC (consumer and commercial solvents, and architectural surface coatings).

Onboard controls on motor vehicles to capture gasoline vapor during refueling.

Stage II control devices on gas pumps to capture gasoline vapor during motor vehicle refueling.

Fuel volatility controls which limit the rate of gasoline evaporation.

Enhanced inspection and maintenance (I/M) programs for cars and light-duty trucks.

New highway-vehicle emission standards for passenger cars and light-duty gasoline trucks.

Methanol fuels as a substitute for gasoline as a motor vehicle fuel.

Table 3-12. Estimated Cost-Effectiveness of Selected Control Strategies Analyzed by OTA
(dollars per ton of VOC reduced)

	1 9 9 3			1 9 9 8			2 0 0 3		
	Nonattainment Cities	Attainment Areas	Nationwide	Nonattainment Cities	Attainment Areas	Nationwide	Nonattainment Cities	Attainment Areas	Nationwide
RACT	2,900-7,200	--[a]	--	3,000-7,300	--	--	3,200-7,300	--	--
New CTGs	5,000-7,300	--	--	5,100-7,300	--	--	5,100-7,400	--	--
Federal Controls	1,700	1,700	1,700	1,700	1,700	1,700	1,700	1,700	1,700
Onboard	1,100-1,300	1,100	1,100-1,300	1,200-1,400	1,200	1,200-1,400	1,200-1,400	1,200	1,200-1,400
Stage II	1,000	--	--	1,000	--	--	1,000	--	--
Stage II & Onboard	1,200	1,100	1,200	1,700	1,200	1,500	1,900	1,200	1,600
Enhanced I/M[b]	2,500-5,100	--	--	3,200-6,400	--	--	3,400-6,800	--	--
Fuel Volatility[c]	320-700	320-700	320-700	320-700	320-700	320-700	320-700	320-700	320-700
New Highway Vehicle Std's[b]	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400
Methanol Fuels	39,000	--	--	39,000	--	--	39,000	--	--

[a] "--" means control strategy is applied only in nonattainment cities.

[b] Estimates reflect costs associated with VOC control only. Enhanced I/M controls also applies to NO_x and carbon monoxide emissions; new highway vehicle standards also apply to NO_x emissions.

[c] Estimates reflect cost-effectiveness during the five-month summertime period when controls are required.

Strategy Descriptions

RACT = "Reasonable Available Control Technology" on all existing stationary sources that emit more than 25 tons per year of VOC.

New CTG's = new Control Technique Guidelines for existing stationary sources that emit more than 25 tons per year of VOC.

Federal Controls on selected small stationary sources of VOC (consumer and commercial solvents, and architectural surface coatings).

Onboard controls on motor vehicles to capture gasoline vapor during refueling.

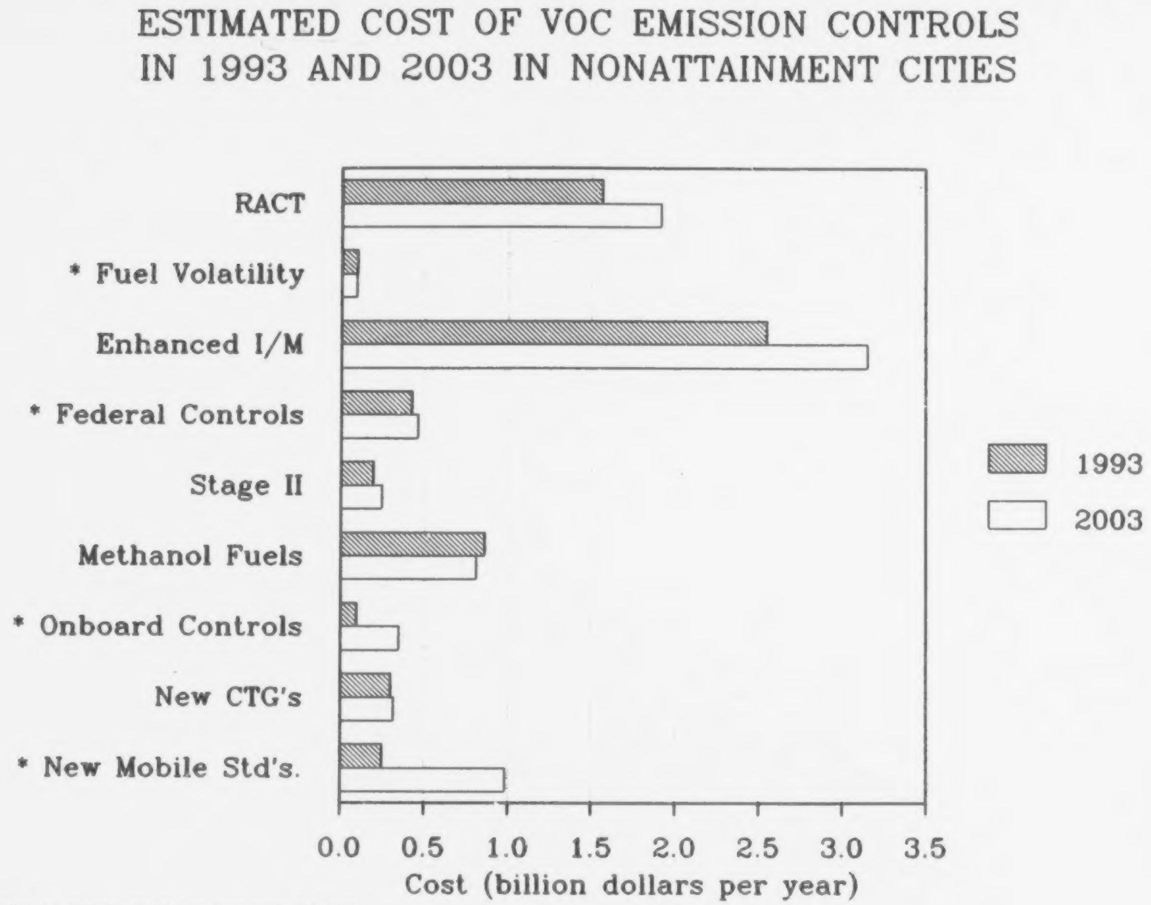
Stage II control devices on gas pumps to capture gasoline vapor during motor vehicle refueling.

Fuel volatility controls which limit the rate of gasoline evaporation.

Enhanced inspection and maintenance (I/M) programs for cars and light-duty trucks.

New highway-vehicle emission standards for passenger cars and light-duty gasoline trucks.

Methanol fuels as a substitute for gasoline as a motor vehicle fuel.



* Costs in attainment areas not shown.

Figure 3-16. Estimated Cost of Volatile Organic Compound (VOC) Emission Control Strategies in 1993 and 2003 in Nonattainment Cities.

The cost of Enhanced Inspection and Maintenance (I/M) programs includes nitrogen oxide and carbon monoxide control. The cost of New Mobile Standards includes nitrogen oxide control.

Strategy Descriptions

RACT = "Reasonably Available Control Technology" on all existing sources that emit more than 25 tons per year of VOC.

Fuel Volatility standards that limit the rate of gasoline evaporation.

Enhanced Inspection and Maintenance (I/M) programs for passenger cars and light-duty trucks.

Federal Controls on selected small stationary sources of VOC (consumer and commercial solvents, and architectural surface coatings).

Stage II control devices on gas pumps to capture gasoline vapor during motor vehicle refueling.

Methanol Fuels as a substitute for gasoline as a motor vehicle fuel.

Onboard controls on motor vehicles to capture gasoline vapor during refueling.

New CTGs = new Control Technique Guidelines for existing stationary sources that emit more than 25 tons per year of VOC.

New Mobile Standards = more stringent tailpipe emission standards for passenger cars and light-duty gasoline trucks.

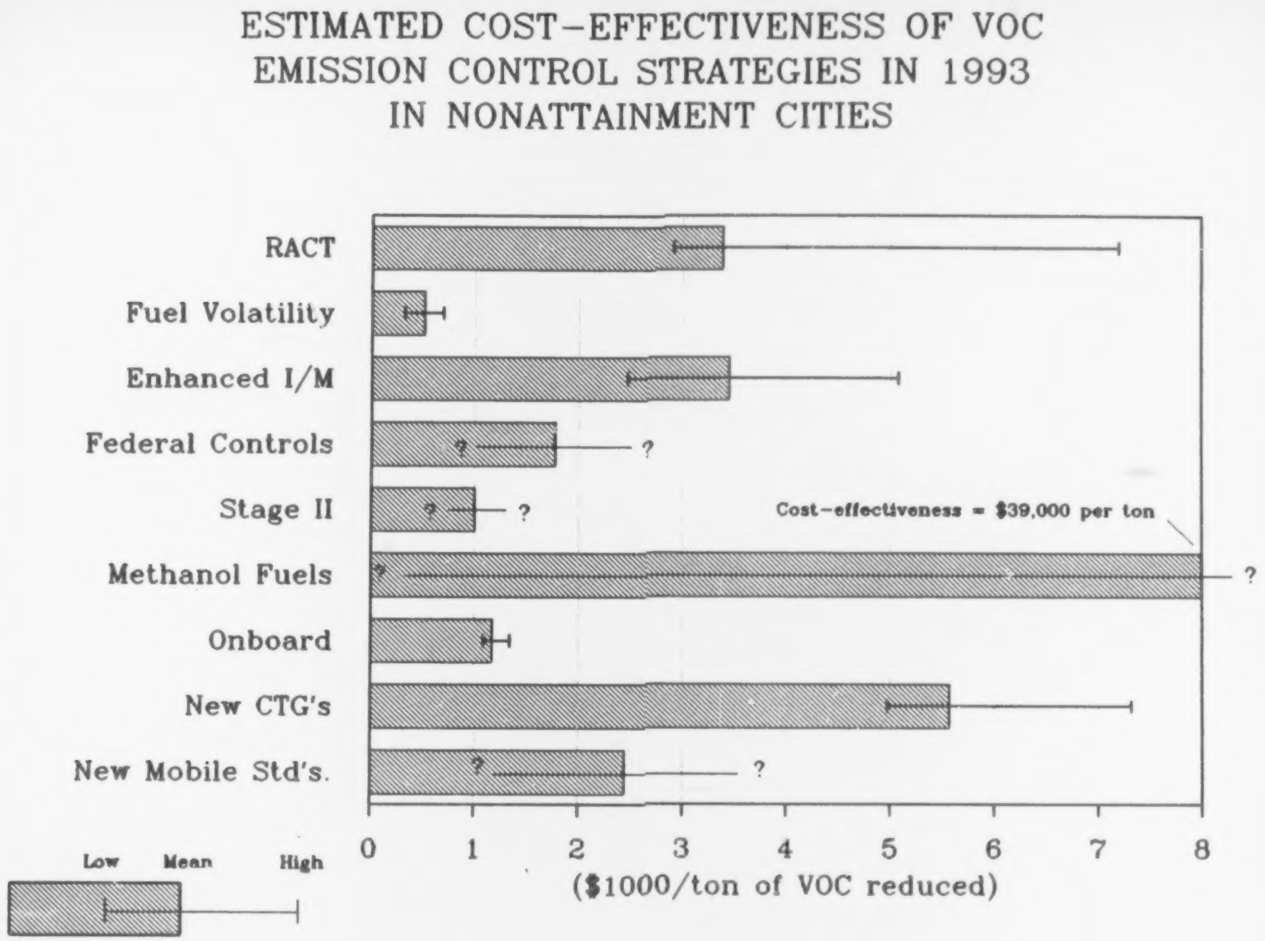


Figure 3-17. Estimated Cost-Effectiveness of Volatile Organic Compound (VOC) Emission Control Strategies in 1993 in Nonattainment Cities.

The cost-effectiveness of Enhanced Inspection and Maintenance (I/M) programs and New Mobile Standards include only the cost of VOC control. The thin horizontal lines represent ranges of uncertainty. The "?" attached to these lines means that calculation of uncertainty was not possible. The very large uncertainty associated with the Methanol Fuels is due to the uncertainty of methanol prices relative to gasoline prices.

Strategy Descriptions

RACT = "Reasonably Available Control Technology" on all existing sources that emit more than 25 tons per year of VOC.

Fuel Volatility standards that limit the rate of gasoline evaporation.

Enhanced Inspection and Maintenance (I/M) programs for passenger cars and light-duty trucks.

Federal Controls on selected small stationary sources of VOC (consumer and commercial solvents, and architectural surface coatings).

Stage II control devices on gas pumps to capture gasoline vapor during motor vehicle refueling.

Methanol Fuels as a substitute for gasoline as a motor vehicle fuel.

Onboard controls on motor vehicles to capture gasoline vapor during refueling.

New CTGs = new Control Technique Guidelines for existing stationary sources that emit more than 25 tons per year of VOC.

New Mobile Standards = more stringent tailpipe emission standards for passenger cars and light-duty gasoline trucks.

Reasonably Available Control Technology (RACT) on All Stationary Sources

Total costs in nonattainment cities for this category are predicted to be about $1.6 billion per year, in 1993, averaging about $2,900 to $7,200 per ton of VOC removed.

As mentioned in an earlier subsection, this control strategy applies to about 39 broad source categories such as petroleum refining, certain types of chemical manufacturing, gas stations, etc. A complete list, with our assumptions about control efficiencies and cost-effectiveness for each source type, is included in Appendix A.

Adoption of New "Control Technique Guidelines" (CTG's)

As stated earlier, we analyzed four stationary source categories currently being considered as candidates for new CTG's: wood furniture coating, plastic parts coating, automobile refinishing, and coke-oven byproduct plants.

We estimate that new CTG's would cost about $300 million per year in 1993, all of which would be incurred in nonattainment cities. The cost-effectiveness averages about $5,600 per ton with a range of $5,000 to $7,300 per ton.Appendix A lists the cost assumptions used in our analysis.

Federal Controls on Small VOC Sources

The small amount of cost data available for architectural surface coatings revealed a wide range of estimates, from a net *savings* to default costs of $2,000 per ton of reduction. We assume that controls for this source cost about $1,000 per ton of VOC reduced. For commercial and consumer solvents we assume a default cost of $2,000 per ton.

We estimate that, in 1993, federal controls on small VOC sources would cost about $810 million per year, nationwide, with about $420 million per year incurred in nonattainment cities. The average cost-effectiveness is estimated to be about $1,700 per ton of VOC removed.

Controls on Gasoline Emissions From Vehicle Refueling

"Onboard" refueling controls on motor vehicles

We estimate the cost of Onboard controls by 1993 to be about $190 million per year, nationwide, with about $90 million per year incurred in nonattainment cities. By 2003, costs would total $720 million per year, nationwide, because of the higher percentage of Onboard-equipped vehicles on the road. The average nationwide cost-effectiveness is estimated to be about $1,100 per ton in 1993.

For this analysis, we assume that all gasoline vehicles manufactured in 1991 and later will be equipped with Onboard controls to capture gasoline vapors during refueling. By 2003, all gasoline vehicles on the road will be equipped with these controls. We assume that Onboard controls cost about $25 per vehicle, which is close to EPA's upper bound estimate[57]. Note, however, that others conclude that the costs are higher. A study for the Motor Vehicle Manufacturers Association estimates average per-vehicle costs of $80 for model-year 1991 vehicles.[58]

"Stage II" refueling vapor recovery

We estimate the cost of Stage II controls to be about $190 million per year in 1993, all of which is incurred in nonattainment cities. This estimate is based on a cost-effectiveness of $1,000 per ton of VOC removed. This figure represents EPA's upper bound range as presented in the recent gas-marketing regulatory impact analysis.[59]

Combined Stage II and Onboard controls

We assume that the cost of a combined Stage II and Onboard program is the sum of the cost of each individual program. Therefore, in 1993, we estimate the cost to be about $380 million per year, nationwide, with approximately $280 million per year incurred in nonattainment cities. Nationwide costs increase to about $960 million per year in 2003. The nationwide combined cost-effectiveness in 1993 is estimated to be about $1,200 per ton of VOC removed and is expected to increase to about $1,600 per ton by 2003 because of fleet turnover.

Enhanced Motor Vehicle Inspection and Maintenance (I/M) Programs

We estimate that enhanced I/M programs in nonattainment cities cost between about $2.1 billion and $3.0 billion per year. In 2003, costs are expected to rise to between about $2.6 billion and $3.7 billion per year. Assuming that one-third of the total costs are for VOC reductions (the other two-thirds for NO_x and carbon monoxide), the cost-effectiveness in 1993 is estimated to be between $2,500 and $5,100 per ton of VOC reduced. In 2003, the cost-effectiveness will increase to between $3,400 to $6,800 per ton; this rise is due to the fact that cars and trucks will be cleaner in 2003, thus lowering the emission reduction potential of enhanced I/M programs.

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[57] U.S. Environmental Protection Agency, op.cit., footnote 41, p. 2-51

[58] Multinational Business Services, Inc., "Costs and Cost-Effectiveness of Stage II and Onboard Refueling Vapor Controls," prepared for the Motor Vehicle Manufacturers Association of the United States, Inc., and the Automobile Importers of America, Inc., April 1987, p. 4-14.

[59] U.S. Environmental Protection Agency, op.cit., footnote 41.

Our estimates of enhanced I/M program costs are based on an analysis of the California I/M program, prepared for the California Air Resources Board by Sierra Research, Inc.[60] We use Sierra Research's finding that an enhanced I/M program costs about $50 per vehicle. About $20 of this cost is for the inspection fee and program administration. The remainder is for repair costs, which we assume to range between $70 and $100 per vehicle for one-third of the vehicles inspected. Sierra Research's analysis concludes that an enhanced I/M program can reduce VOC emissions from cars and light-duty trucks by about 30 percent. This is about 17 percent higher than current I/M programs. For those cities that already have an I/M program in place, we credit $20 per vehicle as the cost of the existing program.

These costs are quite a bit higher than EPA estimates.[61] The major difference seems to be assumptions about whether repair costs drop after the program has been operating a few years.

More Stringent Highway-Vehicle Emission Standards

We estimate that the total cost of tighter emission standards for highway vehicles in 1993 will be about $580 million per year, nationwide, of which about $250 million per year will be incurred in nonattainment cities. By 2003, costs will total about $2.3 billion per year, nationwide, because a higher percentage of vehicles on the road will be equipped with new controls. These totals include the costs attributed to both VOC and NO_x control on new passengers cars and light-duty gasoline trucks. Costs are based on an OTA contractor report by Sierra Research, Inc. (1988), that estimated new emission control costs of about $140 per vehicle for combined VOC and NO_x control.[62] Reductions of VOC are estimated to cost about $2,400 per ton of VOC reduced. (The cost-effectiveness of combined VOC and NO_x control is about $9,200 per ton of VOC and NO_x reduced.) As described earlier, we analyzed more stringent standards that can be met after 50,000 miles of driving under *controlled* conditions for cars, and 120,000 miles for light-duty trucks; tailpipe VOC emissions may exceed these standards after 50,000 miles (for cars) and 120,000 miles (for trucks) of *actual* use by individual vehicle owners.

Limits on Fuel Volatility

We estimate that reducing fuel volatility (i.e., the rate of evaporation) during the five-month summertime period costs between about $150 million and $340 million per year nationwide. The cost-effectiveness, as estimated by EPA, ranges between about $320 to $700 per ton of VOC reduced.[63]

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[60] Sierra Research, Inc., op. cit., footnote 44.

[61] Phil Lorang, U.S. Environmental Protection Agency, Office of Mobile Sources, "Further OMS Reflections on the Cost of Mobile Source Provisions of the Mitchell Bill," September 10, 1987.

[62] Sierra Research, Inc., op. cit., footnote 44.

Alternative Motor Vehicle Fuels: Methanol

Because methanol is incompatible with some metals and polymers currently used in automotive fuel systems, straight methanol is not recommended for use in vehicles designed to run on gasoline. However, methanol-fueled vehicles have been built in limited runs and are currently being test driven in California. Automobile manufacturers estimate that in runs of less than about 150,000 vehicles, passenger vehicles designed to operate on methanol would cost $500 to $1,000 more per vehicle than gasoline-fueled vehicles.[64] Assuming that using methanol is equivalent to reducing total VOC emissions by 50 percent, compared to a new gasoline-fueled vehicle with refueling controls in place, and that methanol-fueled vehicles cost $500 to $1000 more than comparable gasoline-fueled vehicles, the costs associated with a methanol strategy would be roughly $10,000 to $20,000 per ton of VOC removed[65], not considering fuel costs. However, in large runs, others expect the costs of producing gasoline and methanol-fueled vehicles to be comparable, so that considering vehicle costs alone, the cost per ton of VOCs removed would be negligible.[66]

Based on estimates of the retail cost of methanol ($0.84 per gallon[67]) and the 1987 average retail price of gasoline ($0.96 per gallon[68]), and assuming that gasoline mileage is 1.8 times better than that of methanol, we estimate that fuel costs for operating motor vehicles on methanol would be about 50 percent higher than operating them on gasoline: 5.7 cents per mile for methanol versus 3.6 cents per mile for gasoline. Retail gasoline prices would have to rise above about $1.50 per gallon with no change from current prices for methanol in order for gasoline and methanol fuel costs to be equal.[69] Again assuming that methanol use is equivalent to reducing VOC emissions by 50 percent, the existing difference in fuel prices would result in emission reduction costs of about $39,000 per ton of VOC removed, above vehicle costs.[70] Based on this cost effectiveness estimate, the total cost of a strategy in which centrally owned light-duty vehicles in areas with design values of 0.18 ppm or higher would be required to operate on methanol is estimated to be $860 million, in 1993. Finally, note that the cost effectiveness of methanol use is highly sensitive to the relative prices of methanol and gasoline. If retail methanol prices were ten cents lower than assumed above, for example, the estimated cost per ton of VOC removed would be reduced by one third, to about $26,000.

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[63] U.S. Environmental Protection Agency, op. cit., footnote 48, pps. 6-26, 6-28.

[64] "Cost and Cost Effectiveness of Alternative Fuels," prepared for the Vice President's Task Force, July 1987.

[65] Assuming new gasoline-fueled vehicles emit 0.95 g/mi.

[66] Ibid.

[67] Based on current wholesale methanol costs of $0.60 per gallon (Alcohol Update, Information Resources, Inc., Washington DC, April 11, 1988), and $0.24 per gallon for taxes, distribution and markup.

[68] Monthly Energy Review, U.S. Department of Energy, DOE/EIA-0035 (87/10), Washington DC, October, 1987, p. 96.

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[69] The amount of methanol required to operate centrally owned fleets of 10 or more light duty vehicles year round in all areas with design values of 0.18 ppm or higher is estimated to be about 2.8 billion gallons per year. This level of methanol consumption is more than twice current U.S. production. Moreover, existing methanol production capacity worldwide is insufficient to meet this demand. Because new facilities for methanol production are unlikely to be profitable if methanol prices drop much below current levels, significantly lower methanol prices are not expected in the future.

[70] In estimating cost effectiveness it is assumed that a gasoline-fueled vehicle would get 27 miles per gallon, and emit a total of 0.95 grams VOC per mile.

4. OZONE AND THE CLEAN AIR ACT

The goal of the Clean Air Act is to "protect and enhance the quality of the Nation's air resources." To implement that goal, the 1970 Clean Air Act Amendments required EPA to establish National Ambient Air Quality Standards (NAAQS) to define the level of air quality that is expected to be maintained throughout the nation. Of the six "criteria" pollutants[1] for which standards have been established, we have been least successful in our efforts to attain the standard for ozone. Nationwide, more than sixty areas still violate the ozone standard.

The ozone nonattainment problem is addressed by bills in both houses of Congress, as well as by a new regulatory policy that has been proposed by EPA. In this chapter, we first review the framework for meeting the ozone standard that was established in the 1970 and 1977 Clean Air Act Amendments and then briefly discuss the State implementation planning (SIP) process. The last section presents some of the reasons why efforts to meet the standard following the 1977 Amendments failed.

4.1 Evolution of Ozone Control Under the Clean Air Act:

The 1970 and 1977 Clean Air Act Amendments established a partnership between the States and the Federal Government. EPA sets nationally uniform air quality standards and the States, with the Agency's assistance, are responsible for meeting them. The requirement that the States develop "State Implementation Plans" (SIPs) and submit them to EPA for review allows for federal oversight of the States' efforts to achieve and maintain the required level of air quality. In addition to the SIP process, the 1970 Clean Air Act Amendments established two mandatory control programs, one applying to new motor vehicles and the other to new stationary sources. EPA is responsible for setting standards for new motor vehicles. EPA also issues regulations for new stationary sources, but the program is implemented by the States. The 1977 Amendments added three additional control programs, requiring ozone and carbon monoxide nonattainment areas to apply retrofit controls on existing stationary sources and more stringent emissions limits on new stationary sources, and to develop motor vehicle inspection and maintenance programs.

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[1] The six "criteria" pollutants for which EPA has been explicitly required to establish NAAQS are ozone, lead, sulfur dioxide, particulates, nitrogen dioxide, and carbon monoxide.

As defined in the Clean Air Act, "primary" air quality standards represent the maximum allowable concentration of each criteria pollutant that protects against adverse health effects. The primary standards are required to be set at a level that "protects the public health" with an "adequate margin of safety," without regard to the economic or technical feasibility of attainment. Secondary standards are established to protect against adverse impacts on human comfort and welfare, including impacts on visibility, vegetation, animals, wildlife, materials and property. The States, together with EPA, are responsible for ensuring that the primary air quality standards are met "as expeditiously as practicable", within the deadlines specified in the Act. The secondary standards are to be attained in a "reasonable" period of time.

Primary and secondary standards for *oxidants*[2] were first set by EPA in 1971. In 1979, EPA revised the standards to the current definition. Both the primary and secondary standards for *ozone* are currently defined as a daily maximum, one-hour average concentration of 0.12 ppm, not to be exceeded more than once per year, on average.

In the Clean Air Act Amendments of 1970, Congress set 1975 as the deadline for meeting the primary air quality standards. The States were required to develop and carry out State Implementation Plans (SIPs), estimating the emissions reductions required to attain the NAAQS, and establishing control programs to achieve the required reductions. In addition, EPA was required to develop New Source Performance Standards (NSPS) that would be imposed on new or modified stationary sources with the potential to emit more than 100 tons per year of any of the criteria pollutants or of volatile organic compounds (VOCs), one of the two principal precursors of ozone. To enforce the NSPS, the States were required to include construction permit programs in their SIPs. EPA was also required to enforce a specified schedule for reducing emissions from motor vehicles.

By 1977, two years after the original deadline, 78 areas were still violating the ozone standard then in place (no more than one exceedance per year of a one-hour average oxidant concentration of 0.08 ppm). The widespread failure to attain the ozone standard by 1977 has been attributed to the fact that mobile source emissions reductions that the States and EPA were counting on to reduce ozone were not fully realized[3], and that few controls were required on existing stationary sources of VOCs[4]. Due to waivers granted by the EPA Administrator and an extension given by Congress, the schedule specified in the Clean Air

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[2] Photochemical oxidants are a group of chemically-related pollutants. From the standpoint of health and welfare effects, ozone is the most important of these pollutants. Ozone typically comprises over 90 percent of the total mass of photochemical oxidants measured in urban air.

[3] Stewart, R.B. and Krier, J.E., Environmental Law and Policy, 2nd Edition (Bobbs-Merrill Company, Inc., Indianapolis, IN, 1978).

[4] Hawkins, D., personal communication, March 1988.

Act for tightening motor vehicle emissions limits had not been met. For example, while new car VOC emissions rates were about 60 percent lower in 1977 than in 1970, according to the schedule specified in the Act, a 90 percent reduction should have been achieved. Transportation control measures such as gas rationing, restricted parking and restricted freeway lanes generally met with strong resistance; and in 1974 Congress enacted legislation that prohibited EPA from requiring many types of transportation control measures.

In 1977, the deadline for meeting the ozone standard was moved back to 1982. Severe nonattainment areas that did not expect to be able to meet the 1982 deadline could obtain an extension to 1987. Responding to the failure to meet the goals of the 1970 Clean Air Act, the 1977 Amendments included a new and more aggressive control program. New SIPs were to be developed and submitted to EPA in 1979, and again in 1982, for areas seeking extensions of the attainment deadline to 1987. A new schedule was established for imposing emissions limits for new motor vehicles. Existing stationary sources in nonattainment areas would have to be retrofit with emissions controls. A new source could only be constructed in a nonattainment area if it would operate at the "lowest achievable emissions rate" and if emissions reductions could be obtained from other sources to offset the emissions from the proposed source. Transportation control measures would have to be considered. Severe nonattainment areas would have to implement automobile inspection and maintenance programs.

By 1983, 17 areas that had not asked for extensions to 1987 were still violating the ozone standard (which had by that time been revised to its current definition, a daily peak one-hour average concentration of 0.12 ppm not to be exceeded more than once per year, on average). Following its interpretation of the Act, EPA proposed to ban construction of major stationary sources in these areas. However, Congress then prohibited the Agency from using appropriated funds to impose construction moratoriums in areas with approved SIPs. Consequently, the areas that had not met the 1982 deadline were simply required to submit revised SIPs demonstrating how they would attain the standard by 1987. As of November, 1987, no final action had been taken to approve or disapprove any of these SIPs. Since 1983, the Agency's policy on sanctions has been to restrict their imposition to areas with deficient SIPs or areas that have failed to carry out their SIP commitments in good faith.

In addition to the 17 areas that were supposed to meet the 1982 deadline but failed to do so, approximately forty ozone nonattainment areas had obtained deadline extensions prior to 1982. These areas were to have submitted SIPs in 1982 that would demonstrate attainment by 1987. EPA promulgated approvals and disapprovals for most of these SIPs in 1983 or 1984. Sanctions were imposed in some areas to spur correction of SIP deficiencies. In July of 1987, EPA proposed construction bans for 11 ozone nonattainment areas that still did not have adequate SIPs.

Some progress has been made since 1977 in reducing emissions of VOCs, one of the two principal sets of precursors of ozone. Nationwide, estimated emissions of VOCs have decreased by about 10 percent over the last decade. The decline in VOC emissions is due primarily to a 30 percent decline in mobile source emissions, which has occurred because of significant reductions in vehicle emissions rates, despite a 25 percent increase in vehicle miles traveled.[5] Stationary source VOC emissions have increased by about 3 percent since 1977.

Emissions of nitrogen oxides (NO_x, the other principal set of precursors of ozone) are estimated to have declined by less than two percent.[6]

Despite the progress that has been made in reducing VOC emissions, more than 60 areas still violate the current ozone standard. In November, EPA proposed a "post-1987" policy for addressing ozone and carbon monoxide nonattainment. Then, on December 11, 1987, Congress extended the deadline for attainment once again, this time to August, 1988. The legislation precluded the imposition of the construction bans EPA had proposed in July.

4.2 State Implementation Plan (SIP) Development and Implementation

The principal regulatory mechanism by which the air quality standards are to be met and maintained is the State-level process of developing and implementing State Implementation Plans (SIPs). Through the SIP process, the States determine the emissions reductions required to meet the air quality standard and then set up programs to achieve the required reductions. EPA is responsible for reviewing the SIPs to ensure that they will lead to attainment, and also provides guidance to the States on several aspects of SIP development. In addition to deadlines for attainment of the standards, Congress has also specified deadlines for SIP development.

Developing and implementing a State Implementation Plan for ozone involves a series of steps that are carried out primarily at the State and local levels.

1) First, the extent and severity of the local air quality problem is determined by monitoring ambient ozone concentrations. An area is classified "nonattainment" for ozone if peak one-hour average concentrations measured at any monitor exceed 0.12 ppm more than one day per year, averaged over three years.

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[5] U.S. Environmental Protection Agency, National Air Quality and Emissions Trends Report, 1985, EPA-450/4-87-001 (Research Triangle Park, NC, 1987), pp. 3-32, 3-35.

[6] Ibid., p. 3-29.

2) A critical piece of information required to develop a strategy for meeting the ozone standard is an inventory of VOC and NO_x emissions that covers both stationary and mobile sources. The first step is to estimate current emissions of both precursors. The second is to forecast the changes in emissions that are anticipated to occur in the future without additional local control efforts. Such changes include increases or decreases due to anticipated changes in population, motor vehicle use and industrial activity, and also reductions due to control programs which will be implemented at the federal level.

3) The next step is to use a mathematical model to predict how much emissions will have to be reduced (in addition to the reductions that will be achieved through federally-implemented control programs) to meet the ozone standard by the Congressionally-specified deadline. The predicted control requirement becomes the emissions reduction target for the area.

4) The three preceding steps are technically challenging. The fourth step is difficult not only from a technical standpoint, but also from a political standpoint. Each nonattainment area must develop a control strategy that allocates the required emissions reductions among sources in the area, and then design programs to carry out the strategy. A control strategy typically includes imposition of emission limits or control technology requirements on stationary sources, with permitting and source inspection and monitoring programs to ensure compliance. Control strategies may include measures to encourage people to cut back on driving. Retrofit controls on some categories of stationary sources, new source construction permitting programs and motor vehicle inspection and maintenance programs have been specified by Congress as mandatory components of SIP control strategies for ozone.

5) Once an ozone control strategy has been developed, the regulations contained in the SIP must be approved through the State regulatory process, and in some cases, by the State legislature. This step alone can be time consuming. State rulemaking processes typically take from six to eleven months[7].

6) Once a SIP has been approved at the State level, it is sent to EPA for review. The Agency ensures that the SIP has made the required "attainment demonstration", i.e. that the control measures the State has committed to implementing will provide the level of emissions reductions predicted to be required to meet the standard. The Agency also ensures that the SIP includes all of the control programs that Congress

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[7] Pacific Environmental Services, Inc., Study of the 1979 State Implementation Plan Submittals (prepared for the National Commission on Air Quality, Washington, D.C., December 1980), pp. 4-13, 4-14.

requires. If the States are delinquent in their submittals or submit deficient SIPs, the Agency is required to impose specified sanctions and may impose others at its discretion.

7) The first six steps can be regarded as SIP development. What remains is to carry out the regulatory programs contained in the SIP. This includes operating inspection, monitoring, and enforcement programs for both stationary and mobile sources. As SIP implementation progresses, the impact of the SIP is assessed by tracking emissions, and ultimately through monitoring ambient ozone concentrations.

8) Finally, the control strategy is revised, if necessary, to resolve problems identified by EPA during its review process, or to compensate for inaccurate predictions of emissions trends or of the efficacy of control measures, or, finally, if the ozone standard is not attained.

EPA participates in SIP development by providing guidance to the States on monitoring, emissions inventory development, modeling, and on the cost and reduction potential of alternative control measures. Most States rely heavily on EPA as a source of this information. For ozone, the "control technology guidelines" (CTGs) issued by EPA on retrofit control strategies for existing sources of VOCs have been particularly critical. States have not only relied on the CTGs to help identify potential VOC control measures but also to facilitate promulgation of State-level regulations. For example, the existence of a CTG for a particular source can provide leverage in convincing State legislators that the source ought to be controlled.

EPA is responsible for reviewing the SIPs to ensure that they will lead to attainment by the specified deadline and that they contain the required control programs. This process involves repeated interaction between EPA, its Regional offices, and the States.

4.3 Failure to Meet the Ozone Standard Following the 1977 Amendments

More than ten years have now gone by since the passage of the last major set of amendments to the Clean Air Act, which called for a new and more aggressive control program to attain the ozone standard throughout the country by 1987. While ozone concentrations have been lowered in many nonattainment areas, more than 60 areas still exceed the standard. OTA sponsored two workshops involving State and local air pollution control agency officials and current and former EPA staff, respectively, to explore the reasons why this decade-long effort has not resulted in more areas attaining the standard.

Before each of the workshops, participants were asked to complete a questionnaire that suggested possible problems associated with the development and implementation of the ozone control strategy pursued since the late 1970s. The results of the questionnaires formed the basis for further discussion.

Participants at each workshop tended to agree on a few problems that they saw as most significant. However, the problems emphasized by EPA and State regulators were quite different. State and local respondents emphasized the problems of transport of ozone and ozone precursors, inadequate air quality models, States' inability to promulgate regulations without EPA support, and inadequate EPA performance. EPA respondents most often cited emissions growth, inaccurate emissions inventories, unreasonable deadlines in the Act, and "lack of political will" to solve the ozone problem.

Many of the key problems identified in the OTA workshops were similar to those discussed in a recent GAO report.[8] The GAO investigators also identified problems stemming from inaccurate emissions inventories, flawed modeling, and ineffective EPA oversight. In addition, they found that some control measures planned by States were not implemented or were poorly enforced.

In this section, we will summarize the reasons for continued nonattainment most often suggested by participants in the OTA workshops and in the GAO report. Our discussion begins with "planning" problems, such as inadequate inventories and poor modeling, and continues with the more difficult administrative and political problems, such as the slow pace of issuing control regulations and poor control over emissions growth.

Incomplete And Inadequate Emissions Inventories

An early and extremely important step in developing an ozone control strategy is to estimate current emissions of ozone precursors and to project future emissions in the absence of additional controls. Both EPA and State participants at the OTA workshops suggested that incomplete or inaccurate emissions inventories were a very serious problem. Respondents were particularly concerned that emissions projections made in the past have been too low, thus leading to underestimation of the reductions needed to ensure attainment by 1987. State respondents emphasized that when current SIPs were developed, regulators did not anticipate the gradual increase in gasoline volatility and hence evaporative emissions that has since occurred. EPA participants stressed that in many areas, growth in automobile use has been much higher than originally expected, and as a result automobile emissions have exceeded expectations.

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[8] United States General Accounting Office, 1988, "Air Pollution: Ozone Attainment Requires Long-Term Solutions to Solve Complex Problems". GAO/RCED-88-40, 61 pp.

The GAO investigators agreed that the ozone plans they reviewed often understated VOC emissions. For example, they found that "the plan for the Los Angeles area estimated that vehicle mileage would increase 14 percent for the planning period, but the mileage actually increased during the 1979 to 1985 period by 26 percent."[9]

Underestimates Of The Extent Of Control Required To Attain The Standard

The next step in devising a control strategy is to estimate the extent of emissions reductions necessary. Ozone is formed by a complex series of reactions involving volatile organic compounds (VOCs) and nitrogen oxides (NOx) in the presence of sunlight. In order to control ozone formation, one must decide how much to reduce emissions of VOCs or NOx, or both. To do so, regulators have relied on atmospheric models that describe the relationship between VOC and NOx emissions and ambient ozone levels. Since each nonattainment area is unique due to a different mix of sources and different meteorological conditions, relying on computer models to predict control requirements allowed regulators to tailor control programs to each area's local circumstances.

State and local participants at the OTA workshops suggested that inaccuracy and misuse of atmospheric models were among the most significant problems that contributed to continued nonattainment. They suggested that, due to incomplete scientific understanding of ozone formation, available atmospheric models were (and still are) too inaccurate to derive accurate estimates of the emissions reductions needed to ensure attainment. State participants suggested that state-of-the-art models, which they believe are accurate to within 30 percent at best, are not sufficient to ensure compliance with a standard that allows only three exceedences over a three-year period.

State participants suggested that a second problem with models was that delegation of responsibility for applying models to the States provided them with ample opportunities to cheat in developing their implementation plans, a practice known as "gaming". States were able to choose favorable model assumptions and inputs to arrive at the least stringent predictions of emission reduction requirements.

Many State participants were also concerned that available models do not adequately account for transport of ozone and its precursors. Finally, State workshop participants questioned whether NOx emission reductions may have been needed in addition to the VOC reductions, which EPA has exclusively encouraged.

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[9] Ibid., p.29

In contrast to State and local workshop participants, EPA participants were relatively comfortable with available air quality models. They suggested that uncertainties in modeling are no greater than the uncertainties associated with many other steps of devising and enforcing an ozone control strategy. EPA respondents were also much less concerned than their State and local counterparts with whether NOx reductions were needed, although they did suggest that NOx controls might be beneficial in a few areas. However, some EPA participants, like their State counterparts, were concerned that available models do not adequately account for transport.

The GAO investigators pointed out the problems that resulted from the use of modeling with incorrect or inadequate data when preparing SIPs. For example, they pointed out that Houston's 1982 SIP indicated that they needed a 41 percent reduction to attain the standard, but that the analysis relied on some poor quality atmospheric data. When the same analysis was performed by EPA with more accurate data, a 71 percent reduction was predicted to be required.[10]

States Had Difficulty Issuing Stationary Source Regulations

Once the magnitude of overall reductions needed has been established, State regulators must decide which sources or source categories will be required to lower emissions, and by how much. EPA provides States with technical guidance concerning the availability and cost of various control measures for new and existing sources. For 29 categories of existing sources of VOCs, the agency issued Control Technique Guidelines (CTGs) that presumptively define the level of controls that EPA considers "reasonably available" (the level of control required for existing sources under the Act). The actual regulations limiting emissions from both new and existing sources were issued by the States. States were required to include regulations corresponding to the CTGs in their SIPs, plus any additional regulations needed to achieve the standard.

State workshop participants pointed out that in many cases reductions due to CTGs alone were not sufficient to attain the standard. They argued that they were unable to promulgate the additional regulations necessary to achieve the requisite VOC emission reductions. First, they suggested that many State regulators face legislative prohibitions or political pressure not to adopt particular control measures unless they are clearly forced to do so by EPA. Second, they suggested that State agencies often do not have the resources or technical expertise needed to develop new regulations on their own. State participants complained that EPA stopped issuing CTGs in recent years, leaving them without a clear federal directive to issue particular regulations and without the resources to develop their own regulations. They also argued that it is more resource efficient for EPA to develop regulations or CTGs once than for each State to duplicate the activity.

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[10] Ibid., p.35

In their own defense, some EPA participants suggested that the agency stopped issuing CTGs in the face of OMB resistance. One participant suggested that after OMB reviewed them, the most recent group of CTGs were "so watered down that it may have been better not to issue them." Other EPA participants argued that budget limitations were much more significant than OMB review.

The GAO report provides some specific examples of areas that did not implement all of the measures they needed to attain the standard. The report states that in Los Angeles, about half of the stationary source control measures committed to in their SIP were not implemented as of 1986. GAO concludes that "in general, the measures had not been implemented either because the control technology was not fully developed or the local air quality board considered the measures too costly given the expected reductions."[11]

Poor Control Over Emissions Growth

In order to meet the air quality standard, nonattainment areas needed to both reduce existing emissions and ensure that new sources of emissions were offset by additional reductions from existing sources. EPA respondents most often cited emissions growth as the most important reason for the widespread failure to attain the ozone standard. As suggested above, growth in automobile use was seen as particularly problematic. Although many areas experienced a net decrease in mobile source emissions as a result of more stringent tailpipe emission standards, the reductions were often less than anticipated due to higher than expected automobile use. Workshop participants also stressed that the increasing number of automobiles will eventually reverse the downward trend in mobile source emissions nationwide unless more stringent tailpipe standards are adopted.

EPA respondents were sharply divided over the effectiveness of regulatory measures intended to offset new stationary source emissions. Only "major" new sources, those that emit more than 100 tons per year, have been subject to new source review, which requires them to obtain emissions reductions from existing sources to offset their emissions, and to install the most stringent control technology available. New sources larger than 100 tons per year can avoid new source review by obtaining offsetting reductions to limit the net emissions increase to less than that of a "major" source, a practice called "netting". About half of EPA respondents felt that too many sources have been exempt from new source review. However, others suggested that current new source review adequately counteracts emissions growth or results in only insignificant emissions increases.

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[11] Ibid., p.25

Most State and local workshop participants were dissatisfied with new stationary source controls. They distrust emissions trading, since they feel that most emissions reductions used in "netting" or offsets would have occurred anyway. State participants argued that such reductions should have been "credited toward cleaner air" rather than used to facilitate new emissions.

Inability To Control "Transported" Ozone and Precursors

State and local participants complained about the difficulty of achieving adequate emissions reductions when the geographic characteristics of the problem do not correspond to State boundaries. State and local respondents suggested that many nonattainment areas monitor high levels of ozone precursors and even nonattainment levels of ozone in air masses entering their areas. They argued that emissions in upwind attainment and nonattainment areas contribute significantly to some cities' air quality problems and to elevated ozone levels in rural areas. EPA respondents also ranked transport as a serious problem, although they did not rank it as highly as did State respondents.

Lack of Leadership and Political Will To Solve the Problem

State and local workshop participants complained that EPA has not demonstrated sufficient leadership and commitment to solve the problem. They suggested that EPA "dragged its feet" on decisions to issue federal regulations for fuel volatility, automobile refueling emission controls, and more stringent tailpipe standards. Participants suggested that EPA's indecision discouraged States from developing their own regulations for those particular sources or for other categories that would deliver small benefits in comparison. As discussed above, the States argued that they were often unable to promulgate additional stationary source regulations because EPA stopped issuing CTGs.

In response to these criticisms, EPA respondents suggested several areas in which the States did not require the measures that they should have, citing inadequate automobile inspection and maintenance programs and incomplete SIP implementation as examples. Although they acknowledged that some federal regulations have been delayed, most EPA respondents suggested that earlier issuance of those regulations would not have had a large effect on the overall nonattainment problem.

The GAO report concluded that both State implementation and enforcement of control programs and EPA oversight have not been as effective as they should have been. From their discussions with State and local officials, the GAO investigators concluded that at the local level there has been "a general reluctance to implement control measures that will have a negative impact on economic development or change life-styles."[12] Agreeing with comments made by EPA participants at our workshops, GAO pointed out a number of specific examples of weak implementation, inspection, and enforcement at the State and local level.

Although the Act delegates primary responsibility for developing SIPs and promulgating the necessary regulations to the States, EPA is responsible for reviewing SIPs and overseeing their implementation. The GAO report was critical of EPA's oversight role. In two of the three urban areas they studied, EPA did not enforce requirements that the States stick to their declared schedules of annual emissions reductions. All three areas had problems with their SIPs. Even though EPA was aware of deficiencies, it did not call for SIP revisions in two of the areas and waited until July 1987 to disapprove the SIP submitted by the third area.

EPA participants at our workshops agreed with many of the criticisms of EPA's performance, but stated that they faced serious constraints on their ability to administer the Act. Questionnaire respondents cited inadequate budgets, OMB interference, and lack of political support. Some suggested that there was never really the "political will" to take the steps necessary to solve the ozone problem. Although many EPA participants cited "lack of political will" as a problem, they disagreed over whose will was lacking. Some suggested that there was an implicit understanding between the States and EPA not to push for more aggressive control measures since they felt that they had reached the limits of *public* acceptability. Others suggested that past efforts were not at all aggressive; *administrative* will, not public support, was lacking. Some argued that the change in Administration in 1981 lead to weaker EPA implementation of the Clean Air Act.

Unreasonable Deadlines

Finally, many EPA respondents suggested that the deadlines Congress specified in the 1977 Amendments were simply unreasonable. They argued that widespread failure to attain the standard by December 31, 1987 does not reflect insufficient progress as much as unrealistic expectations. While some suggested that the deadline was only unreasonable for Los Angeles, others felt that it was unrealistic for many areas. Participants at both workshops argued that unreasonable deadlines were counterproductive. They suggested that overly stringent deadlines encouraged States to cheat on their SIPs and EPA to play along with them.

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[12] Ibid., p. 27

5. PROPOSALS FOR CHANGE:

S.1894, H.R.3054, AND EPA'S PROPOSAL

The leading proposals that address the ozone nonattainment problem include: 1) S.1894, a comprehensive set of amendments to the Clean Air Act reported from the Senate Committee on Environment and Public Works; 2) H.R.3054, a bill focusing on ozone and carbon monoxide nonattainment introduced by Congressman Waxman and 39 cosponsors; and 3) EPA's proposed post-1987 ozone policy, as published in the Federal Register on November 17, 1987.

In this chapter, we compare the three proposals in several ways. First, we compare the *overall requirements* adopted by the three proposals. Under this broad category, we discuss:

o *Deadlines*, including schedules for SIP submittals and approvals, and attainment deadlines for the different categories of nonattainment areas established by each proposal.

o *Schedules of emissions reductions.* In addition to the ultimate requirement to attain the standard, the proposals include interim schedules of percentage reductions of emissions and control requirements for specific source categories. We discuss which of these requirements will, in practice, be the driving force behind VOC reductions for each proposal. We then compare the percentage reductions in VOC emissions under the three proposals in 1993, 1998 and 2003, assuming that the requirements can be met.

o *Penalties* in the event of failure, such as sanctions for failing to submit an adequate SIP, penalties for falling behind the required emission reduction schedule, and penalties for not attaining the standard by the specified date.

Next, we compare the details of the *emissions control requirements* included in each of the proposals. We divide the control requirements into five categories, some of which overlap:

o *State-implemented control requirements*, for example, size cutoffs for controls on major stationary sources and stringency of automobile inspection and maintenance programs.

o *Federally implemented, nationwide regulations*, for example, new automobile emission standards or limits on gasoline volatility.

o *NOx controls*. Except for California, the States and EPA have in the past exclusively relied on controlling VOCs for lowering ozone levels. Two of the proposals would require NO_x controls in addition to VOC reductions.

o *Controls in attainment areas in "transport regions"*, for example, in the northeast corridor, where long-distance transport of ozone or precursors may be significantly contributing to nonattainment problems in some areas.

o *Long-term strategies*, i.e., how each proposal addresses new source growth, maintenance of attainment once it is achieved, and such longer-term control approaches as widespread use of alternatively fueled motor vehicles.

Throughout this chapter, we include relevant background information about current implementation of the Clean Air Act, to put the proposals into context.

5.1 Overall Requirements

Attainment Deadlines And Planning Schedules

The 1977 Amendments established two dates by which nonattainment areas were to attain the ozone standard. Areas with less severe problems were to attain the standard within 5 years, by the end of 1982. Those areas that could not attain the standard by the end of 1982 by adopting all reasonably available control measures were given an additional 5 years (until December 1987, the deadline that recently passed).

Of the new proposals, H.R.3054 sets the tightest attainment schedules. Nonattainment areas must meet the standard within 3, 5 and 10 years, depending on the severity of the problem. EPA's post-1987 ozone policy establishes the longest schedules. Rather than establishing absolute attainment deadlines, EPA sets a schedule for emissions reductions under which some of the worst areas might take over 20 years to attain the standard. S.1894 requires areas to attain the standard within 3 to 15 years, depending on the severity of the problem.

Each of the new proposals establishes several categories of nonattainment areas based on: 1) the date by which the area is expected to attain the standard, 2) an area's "design value" -- a measure of its peak ozone concentrations, or 3) a combination of the previous two. Because more stringent control is required in those areas furthest from attainment, more time is allowed to attain the standard. A list of nonattainment areas and their design values can be found in Section 2.2.

The new proposals also set schedules for submittal and approval of SIPs. Again, H.R.3054 sets the tightest schedules, calling for completion of the process within 15 months after enactment. EPA's proposed policy is the longest, allowing about 3 years.

The next two subsections discuss the deadlines included in each of the proposals in greater detail. A later section presents OTA's estimates of the scheduling of emissions reductions under each of the proposals.

Attainment deadlines (by category of nonattainment area):

The three proposals establish the following categories of nonattainment areas and attainment deadlines:

S.1894:

The Senate Environment Committee proposal creates five categories of nonattainment areas, with attainment dates of 1991, 1993, 1998, 2003, and unspecified, depending on the severity of the problem. More stringent controls are required in each successive category.

1) Nonattainment areas with a design value less than 0.14 ppm and that are able to attain the standard by 1991 have the fewest control requirements.

2) Areas with a design value less than 0.18 ppm are presumed to be able to attain by 1993. However, those areas that declare that they cannot attain by 1993 by adopting all of the source-specific controls required for such areas under the bill have until 1998 to attain.

3) All areas with a design value less than 0.27 ppm must attain by 1998.

4) Areas with a design value 0.27 ppm or greater are presumed to be able to attain by 2003.

5) Areas with a design value 0.27 ppm or greater that cannot demonstrate attainment by 2003 may follow a fixed schedule of emissions reductions and more stringent source-specific controls, in lieu of a fixed attainment deadline.

Three year extensions are possible if additional control requirements are met. Areas that receive extensions are to adopt the control requirements of the next highest category.

H.R.3054:

The Waxman bill establishes 3 categories of nonattainment areas with attainment deadlines of 3, 5, and 10 years. Again, more stringent controls are required in each successive category.

1) Nonattainment areas with a design value less than 0.144 ppm must attain the standard within 3 years of enactment.

2) Areas with a design value between 0.144 and 0.18 ppm must attain within 5 years of enactment.

3) Areas with a design value 0.18 ppm or greater must attain within 10 years of enactment.

Areas that cannot attain the standard by the required 3-year or 5-year deadline become subject to the requirements of 5-year and 10-year areas, respectively.

EPA's post-1987 ozone policy:

Unlike the other two proposals, EPA's post-1987 ozone policy contains only one "deadline" -- demonstrating attainment within about 6 years from the time EPA calls for a SIP revision. The proposed policy does, however, establish several categories of nonattainment areas based on whether additional controls are needed to attain the standard, and if so, whether attainment can be demonstrated within the six-year time frame. Rather than establishing attainment deadlines, the categories determine planning requirements and whether EPA will impose certain penalties for failure. EPA's post-1987 policy establishes three major categories:

1) Nonattainment areas with design values less than 0.16 ppm that can demonstrate attainment within about 6 years through existing and federally implemented control measures alone.

2) Areas able to demonstrate attainment within about 6 years by applying additional control measures.

3) Areas not able to demonstrate attainment within 6 years.

Some rural nonattainment areas that exceed the standard because of transport of ozone or precursors from outside of the area are classified separately.

Schedules for SIP submittals and approvals:

Under the 1977 Clean Air Amendments, EPA was to identify and list nonattainment areas by early 1978. The States had to revise plans for each of their nonattainment areas and submit SIPs to EPA by January 1, 1979, about 16 months after enactment. EPA was required to approve or disapprove these plans by June 30, 1979, six months after the States submitted them.

EPA and the States did not succeed in meeting many of the deadlines established in the 1977 Amendments. By April 1980, 15 months after SIPs were due, about 20 percent of the areas had submitted SIPs, half of which were either incomplete or considered deficient by EPA.[1] This failure to have SIPs developed and approved in a timely manner continued through the 1980s.

Table 5-1 displays the SIP actions required of the States and EPA, and compares the amount of time allowed by Congress in the 1977 Amendments to complete these actions with the amount of time it actually took. As the table shows, the time frame specified by the Clean Air Act for the completion of 1979 SIP submittals was substantially exceeded by the States and EPA. Rather than taking a little under two years from enactment to approval or disapproval of a SIP, as required under the 1977 Amendments, the entire process took about three to four and a half years.

The schedules for SIP submittals and approvals under the new proposals follow:

S.1894:

Under the Senate Environment Committee proposal, States must submit revised SIPs for nonattainment areas before 1990. EPA must approve or disapprove the SIP within 6 months after the revision is submitted (no change from current law).

H.R.3054:

Under the Waxman bill, States must submit revised SIPs within 9 months of enactment. EPA must approve or disapprove the SIP within 6 months after the revision is submitted.

EPA's post-1987 ozone policy:

SIPs must be submitted within 2 years from the date EPA calls for revisions. EPA expects to complete review of each SIP within about 1 year after submittal. Nonattainment areas that will require long-term measures to attain the standard may be granted an additional 3 years for final SIP submittal, but must still submit an initial SIP in 2 years.

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[1] PES Study for NCAQ, 1980, p. 4-21.

Table 5-1.--Time Requirements for SIP Process Under the 1977 Clean Air Act Amendments

Action	Required Time	Actual Time	Difference
1. Designation of a State's attainment status.	6 months (from promulgation of Amendments)	8 months	2 months
2. States' development of technical data base.		3 to 6 months minimum; 15 to 24 months maximum[1]	
3. State submission of revised SIP (including development of ozone control strategy and approval of SIP regulations by State or local regulatory agency).	By January 1, 1979 (10 months from attainment designation)	19 to 33 months[2,3,4]	9 to 23 months
4. EPA review and approval or disapproval of SIP.	Act allows 6 months between date SIPs were due (1/79) and date construction ban was to have been imposed (6/79)	9 to 24 months[5]	3 to 18 months
TOTAL TIME	22 months (1.8 years)	36 to 53 months (3.0 to 4.4 years)	14 to 43 months (1.2 to 3.6 years)

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[1] "Study of the 1979 State Implementation Plan Submittals: An Overview of the SIP Review Process at the State Level and the SIPs for Particulate Matter, Sulfur Dioxide and Ozone," Pacific Environmental Services, Inc., for the National Commission on Air Quality, December 1980.

[2] PES, 1980.

[3] To Breathe Clean Air, National Commission on Air Quality, Washington, D.C., March 1981.

[4] Many States started working on SIP revisions as early as 1975 or 1976, about 12 to 26 months before the 1977 Clean Air Act Amendments. This time was not included in the 19-33 month "actual" timeframe listed for Action #3.

[5] NCAQ, 1981; PES, 1980; and comments of participant in OTA "Ozone and the Clean Air Act" Workshop, September 30, 1987.

Schedules Of Emission Reductions

In each of the proposals, the driving force behind emissions reductions is one or more of several types of requirements that must be met by specified dates. These requirements include: 1) source-specific technology or performance standards, 2) area-wide emission reduction requirements, and 3) attaining the standard.

We first present our subjective judgments about which of the requirements will, in practice, be the driving force behind emissions reductions in each proposal. Our judgments are based on two factors: 1) the difficulty of achieving each target by the specified date and 2) the severity of the sanctions for not meeting each of the requirements. We then present estimates of the overall requirements for VOC reductions (as a percentage below 1985 emissions) for each of the three proposals by 1993, 1998, and 2003.

Driving forces behind emission reductions

While none of the proposals alters the Act's ultimate requirement that the standard be attained, the penalty for not attaining the standard by the specified date varies considerably among the proposals. Each of the proposals adds interim requirements and specifies sanctions (again, of varying seriousness) if the requirements are not met by the dates specified.

All three proposals require some or all areas to achieve a set schedule of emissions reductions. Though a requirement for regular increments of emissions reductions was a relatively minor component of the 1977 amendments, it is an important driving force behind all three new proposals.

Both S.1894 and H.R.3054 also include source-specific technology or performance standards, with S.1894 requiring the most source-specific controls of the two. While both S.1984 and H.R.3054 set a series of deadlines for attaining the standard, S.1894's penalties for not meeting the deadline are much more stringent.

Discussions of the driving forces behind reductions in each of the new proposals follow:

S.1894:

Under the Senate Environment Committee bill, the driving force behind emissions reductions varies by the severity of the nonattainment problem. For those nonattainment areas with low design values (less than about 0.14 ppm), the source-specific control requirements are probably the toughest to meet. For most other areas, the bill's requirement for meeting a specified schedule of emissions reductions is probably the most important driving force.

Though the bill sets 1993 as the attainment deadline for many areas, those areas that cannot attain the standard by adopting the source-specific control requirements required under the bill can extend the deadline until 1998. Areas with a 1998 attainment deadline must meet an interim schedule of emission reductions: 33 percent below 1987 emissions by 1992, 50 percent by 1995, and an additional 15 percent each 3-year period until attainment. For most areas, if this schedule is met, attainment by the bill's deadlines is quite possible.

H.R.3054:

The Waxman bill, like S.1894, is driven by different requirements depending on the severity of the nonattainment problem. For those nonattainment areas with design values 0.144 ppm or less, the only requirement is to attain the standard within three years of enactment.

For those nonattainment areas with higher design values, the Waxman bill places its greatest emphasis on the requirement to meet an annual schedule of emission reductions. Under the bill, the Administrator is to specify the reductions each area needs to attain the standard and establish a schedule to achieve the reductions by the attainment deadline. It is this annual schedule of area-wide emission reduction requirements that is the driving force in the bill. Though requirements to actually attain the standard by specified deadlines are included in the bill, penalties for failure to attain the standard are much less severe than the penalties for falling behind the reduction schedule assigned by EPA.

Less emphasis is placed on source-specific control requirements in H.R.3054 than in S.1894. However, the bill specifies a substantial number of source-specific requirements for the worst nonattainment areas, those with design values 0.18 ppm or higher, and for nonattainment areas that have not attained the standard within five years after enactment.

EPA's post-1987 ozone policy:

EPA's post-1987 policy is driven by the single requirement for areas to follow a specified area-wide schedule of emissions reductions. Areas must achieve emissions reductions of 15 percent below 1987 levels by 1993 (not counting reductions from federally implemented measures or pre-1987 control requirements) and an additional 9 percent below

1987 levels every 3 years thereafter until attainment. Like the Waxman bill, it is this schedule of area-wide emission reduction requirements that is the driving force in the EPA policy.

Of the three proposals, the EPA plan includes the fewest source-specific control requirements. EPA believes that current law does not require them to impose sanctions for failure to attain the standard and does not plan to do so.

VOC Emissions Reductions Through 2003:

In this section, we present our estimates of the VOC emissions reductions required under each of the proposals over the next 15 years. In each case, we assume that nonattainment areas will, if given a choice, choose the set of requirements that imposes the *slowest* schedule of emissions reductions possible under the proposal. (Some areas might choose faster schedules to avoid certain source-specific controls often required as a condition for the slower schedule, but such cases are difficult to predict.)

Tables 5-2 through 5-4 show our estimates of the VOC reductions required, as a percent of 1985 emissions, for 1993, 1998, and 2003. These are based on our conclusions about the driving forces behind each of the proposals presented in the previous section, and city-specific analyses of control requirements to meet the standard presented in Chapter 3.

Each table includes separate estimates for four design value categories used in the proposals. (Note, however, that not all categories are used in all proposals.) Where appropriate, we present both an average reduction figure, and under it, a range that corresponds to the variation among all cities in the category. The details of the reduction requirements are presented in a later section of this chapter. Here we present a rough estimate of the total reduction requirements.

Table 5-2 shows the VOC reduction targets for 1993. Overall, the Senate Committee bill requires the highest percentage of VOC emissions reductions by 1993 and the EPA proposal the lowest. This varies by nonattainment category, however, as can be seen in the table and discussed briefly below.

For nonattainment cities with the least severe problem (design values in the range of 0.13 to 0.14 ppm), all three proposals require approximately the percentage reductions in VOC emissions (20 to 40 percent) needed to attain the standard. However, for some areas with design values of 0.13 ppm, the source-specific requirements of S.1894 may result in slightly higher reductions than needed to attain the standard.

Table 5-2--VOC Emission Reduction Requirements by 1993 Under S. 1894, H.R. 3054, and EPA's Post-1987 Ozone Policy

Note that for some categories, cities are allowed to choose either attainment or a percentage emission reduction requirement. Both the average reduction requirement and the range is shown.

Design value category (ppm ozone)	1985 emissions (1000 tons/yr)	To attain the standard (%)	S.1894 (%)	H.R. 3054 (%)	EPA post-1987 policy (%)	Potential reductions from 1985 emissions, based on OTA analysis (%)[a]
0.13 - 0.14	2,200	31 (19-44)	Attainment or 40	Attainment	Attainment or 30 (19-38)	28
0.15 - 0.17	3,600	53 (40-65)	Attainment or 40	Attainment	30 (22-35)	29
0.18 - 0.26	1,100	60 (52-69)	40	30 (26-35)	26 (23-27)	25
0.27 or higher	770	84 (80-90)	40	42 (40-45)	23 (19-25)	22

[a] This column shows the projected VOC emissions reductions (as a percentage of 1985 levels) that each group of cities can achieve by 1993 if all additional mobile and stationary source control strategies we analyzed are adopted in addition to the State and EPA VOC regulations in place in 1985.

Table 5-3.--VOC Emission Reduction Requirements by 1998 Under S. 1894, H.R. 3054, and EPA's Post-1987 Ozone Policy

Note that for some categories, cities are allowed to choose either attainment or a percentage emission reduction requirement. Both the average reduction requirement and the range is shown.

Design value category (ppm ozone)	1985 emissions (1000 tons/year)	To attain the standard (%)	S. 1894 (%)	H.R. 3054 (%)	EPA post-1987 policy (%)
0.13 - 0.14	2,200	31 (19-44)	Attainment	Attainment	Attainment
0.15 - 0.17	3,600	53 (40-65)	Attainment	Attainment	45 (37-51)
0.18 - 0.26	1,100	60 (52-69)	Attainment or 65	Attainment	40 (36-40)
0.27 or higher	770	84 (80-90)	65	Attainment	37 (33-41)

Table 5-4--VOC Emission Reduction Requirements by 2003 Under S. 1894, H.R. 3054, and EPA's Post-1987 Ozone Policy

Note that for some categories, cities are allowed to choose either attainment or a percentage emission reduction requirement. Both the average reduction requirement and the range is shown.

Design value category (ppm ozone)	1985 emissions (1000 tons/year)	To attain the standard (%)	S. 1894 (%)	H.R. 3054 (%)	EPA post-1987 policy (%)
0.13 - 0.14	2,200	31 (19-44)	Attainment	Attainment	Attainment
0.15 - 0.17	3,600	53 (40-65)	Attainment	Attainment	Attainment or 56 (49-62)
0.18 - 0.26	1,100	60 (52-69)	Attainment	Attainment	51 (48-52)
0.27 or higher	770	84 (80-90)	Attainment or 90	Attainment	49 (48-51)

For the next group of cities, those with design values between 0.15 and 0.17 ppm, H.R.3054 requires attainment by 1993. S.1894 presumes attainment by this date, but areas can opt for a later deadline. We estimate that attainment would require VOC reductions in the range of 40 to 65 percent -- a level probably not achievable by 1993. In such a situation S.1894 specifies a minimum of 40 percent emissions reductions. The EPA proposal requires the lowest reductions, between about 20 and 35 percent.

For the next category, cities with design values between 0.18 and 0.26 ppm, S.1894 once again requires VOC reductions of about 40 percent. H.R.3054 requires cities to meet a schedule assigned by EPA, which we estimate as half the reductions needed to attain the standard, or about 25 to 35 percent. The EPA proposal would require reductions in these cities of about 25 percent.

In the cities with the highest ozone concentrations, those with design values above 0.27 ppm, we estimate that both the Senate Committee bill and the Waxman bill require reductions of about 40 percent by 1993. EPA's proposal requires reductions of about 25 percent.

The last column in Table 5-2 repeats our estimates of the reductions achievable from the control strategies we were able to analyze in Chapter 3. Note that by about 1993, all three proposals require emissions reductions about *equal to or greater than* the amount obtainable from the near-term control measures that we were able to identify.

Table 5-3 shows the VOC reductions required by 1998. By 1998, the Waxman bill requires more VOC control in some areas than the Senate committee bill; the EPA proposal requires the least. Under H.R.3054, all areas are required to attain the standard by 1998 or earlier. As shown in the third column of the table, this might require VOC reductions in excess of 80 percent in areas with the highest design values. The Senate Committee bill requires attainment in most areas or minimum emission reductions of 65 percent below current levels. The EPA proposal requires the lowest reductions, in the range of 40 percent. This would bring most cities with design values below about 0.15 ppm into attainment.

Table 5-4 displays the VOC reduction requirements in 2003, 15 years from now. Again, under H.R.3054, all areas are required to have attained the standard by 1998. S.1894 requires attainment or, at minimum, reductions of 90 percent below current levels. The EPA proposal requires reductions of about 50 percent, enough to bring most cities in the two lowest design value categories into attainment.

Penalties In The Event Of Failure

Each of the three proposals specifies penalties in the event of failure to meet its various requirements. All three proposals distinguish between: 1) the failure of a State to submit an adequate SIP or to implement the required emissions reductions and 2) failure to attain the standard by a given date. Failure to meet the first set of requirements leads to serious sanctions in all three proposals. Failure to actually attain the standard by a given date results in penalties under both the Senate bill and the Waxman bill, with the Senate bill's penalties the more severe of the two. The EPA proposal does not include penalties for failure to attain by a set date, only for failure to adequately plan for attainment.

The Senate and House proposals also include penalties or default provisions in the event EPA does not issue control technique guideline documents (CTGs) for several categories of sources. The Senate bill adds a new penalty for owners of stationary sources that fail to implement reductions required in certain situations.

In this section, we present the penalties included in the proposals for each of the four situations mentioned above.

Failure to adequately plan or implement reductions

For failure of a State to submit an adequate SIP by the required date, or failure of a State or local area to adequately implement required emissions reductions, the proposals include the following penalties:

S.1894:

1) Ban on construction or modification of major stationary sources in the nonattainment area. (The ban applies to new sources emitting more than 25 tons per year of VOC or NO_x, and modifications larger than 10 tons per year.)

2) No Federal highway funds other than for safety, mass transit, or transportation improvement projects related to air quality.

3) In areas that choose a deadline later than 1993, no sewer hookups to a publicly owned sewage treatment works unless each ton of VOC emissions from or associated with the sewage treatment plant is offset by 4 tons of reductions elsewhere in the nonattainment area.

H.R.3054:

1) No Federal highway funds other than for safety, mass transit, or transportation improvement projects related to air quality.

2) Each ton of emission increases from new or modified stationary sources must be offset by 5 tons of reductions from other sources in the nonattainment area.

EPA's post-1987 ozone policy:

1) Mandatory ban on construction or modification of major stationary sources in the nonattainment area. (The ban applies to new sources emitting more than 100 tons per year of VOC, and modifications larger than 40 tons per year.)[2]

2) Discretionary ban on federal highway funds other than for safety, mass transit, or transportation improvement projects related to air quality.[3]

3) Discretionary ban on federal sewage treatment grants.[4]

4) Discretionary ban on federal grants to a State's air pollution control agency.[5]

Failure to attain the standard

For failure to attain the standard by the required date, the proposals include the following penalties:

S.1894:

1) Ban on construction or modification of major stationary sources in the nonattainment area.

2) No Federal highway funds other than for safety, mass transit, or transportation improvement projects related to air quality.

H.R.3054:

1) Areas with a design value less than 0.144 ppm become subject to the requirements for areas with a design value between 0.144 and 0.18 ppm,

2) Areas with a design value between 0.144 and 0.18 ppm become subject to the requirements for areas with design values greater than 0.18 ppm,

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[2] Based on Section 110(a)(2)(I) of the current Act, which requires the Administrator to prohibit the construction of major stationary sources in nonattainment areas if a SIP revision is inadequate.

[3] Based on Section 176(a) of the current Act, which requires the Administrator to withhold federal highway funds, except those for safety, mass transit and transportation improvement projects related to air quality. EPA interprets this sanction to be dependent on a discretionary finding by the Administrator that an area failed to make a reasonable effort to submit a plan meeting Part D requirements. EPA's interpretation was recently upheld in court.

[4] Based on Section 316 of the current Act, which allows the Administrator discretion to withhold, condition or restrict federal grants for sewage treatment plant construction.

[5] Based on Section 176(b) of the current Act, which enables the Administrator to halt federal air program grants if a State or local area fails to adequately implement their SIP. EPA has interpretted this sanction to be discretionary. Others argue that it is mandatory.

3) Areas with a design value greater than 0.18 ppm must offset each ton of emissions increases from new or modified stationary sources with 5 tons of reductions from other sources in the nonattainment area.

EPA's post-1987 ozone policy:

None proposed.[6]

Failure of EPA to issue required "control technique guidance" documents

If EPA fails to issue required control technique guidance documents (CTGs) by the required date, the following penalties are proposed:

S.1894:

Sources in the category to which the CTG would have applied are required to reduce emissions by 90 percent from uncontrolled levels.

H.R.3054:

Sources in the category are required to pay an annual fee of $5000 per ton of VOC and NO_x emitted.

EPA's post-1987 ozone policy:

Not applicable.

Failure of stationary sources to control

For failure of stationary sources to implement required reductions, the following penalties are proposed:

S.1894:

In areas with a design value greater than 0.18 ppm, sources that do not reduce emissions by the percentage required for the nonattainment area as a whole are required to pay an excess emissions penalty equal to the cost of control, or an annual penalty of $5000 per ton, whichever is greater.

H.R.3054:

No new penalties proposed.

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[6] Note that GAO believes that Section 110(a)(2)(I) requires the Administrator to prohibit the construction of major stationary sources in this case. EPA has held that this sanction should not apply to areas with approved plans that predicted attainment by the deadline but failed to actually attain the standard by the deadline.

EPA's post-1987 ozone policy:

No new penalties proposed.

5.2 Control Requirements

To help compare the control requirements of the three proposals, we have organized the requirements into five categories. Because air pollution control under the Clean Air Act relies on a partnership between EPA and State and local governments, our first two categories present: 1) controls to be implemented by the States in nonattainment areas and 2) federally implemented controls that apply nationwide.

Three additional categories are then discussed: 1) controls in areas that are currently in attainment, but that contribute to nonattainment in other regions through transport of ozone or the pollutants from which it is formed, 2) controls on nitrogen oxides (previously applied only in California), and 3) long-term strategies to attain or maintain compliance with the standard. The first two, if adopted, would be new additions to the Clean Air Act. The last category is highlighted because of the importance of controlling new sources of emissions (a problem identified as one of the reasons why the 1977 Amendments were less effective than anticipated).

Control Requirements To Be Implemented By States In Nonattainment Areas

In each of the proposals different requirements apply to nonattainment areas depending on their "design value" -- a measure of peak ozone concentrations -- and the date by which they are expected to attain the standard. These categories were presented in a previous section; this section provides details on the controls specified for each category of nonattainment area in the new proposals and under existing law.

Both S.1894 and H.R.3054 require EPA to issue new "control technique guidelines" (CTGs), which establish the level of control considered to be "reasonably available" (reasonably available control technology or RACT) and thus required for stationary sources in nonattainment areas. The requirements for new CTGs are also presented in this section.

As background, we first review the requirements of the current Act. The Clean Air Act Amendments of 1977 created two categories of nonattainment areas. The following State-implemented controls were required under regulations issued by EPA:

1) Areas that could demonstrate attainment by December 1982:

"Reasonably available control technology" (RACT) for all stationary sources of VOC emitting greater than 100 tons per year, for which EPA issued CTGs prior to 1979.[7]

2) Areas that received extensions of the attainment deadline to December 1987 ("extension" areas):

   a) RACT for all stationary sources of VOC for which CTGs have been issued, including those issued 1979 and later.[8]

   b) RACT for all stationary sources of VOC emitting greater than 100 tons per year for which CTGs have not been issued.

   c) Inspection and maintenance (I/M) program for highway vehicles.

   d) "Lowest achievable emission rate" (LAER) of VOC for new stationary sources emitting more than 100 tons per year or modified stationary sources emitting more than 40 tons per year.

The new proposals require the following controls to be implemented by the States in nonattainment areas:

S.1894:

The Senate Environment Committee proposal creates five categories of nonattainment areas, with the following State-implemented controls required:

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[7] Prior to 1979, EPA issued the following CTGs, which presumptively determine RACT:
1) Surface coating regulations, including CTGs for coating cans, coils, paper, fabrics, autos and light duty trucks, metal furniture, magnet wire, large appliances, flatwood paneling, and miscellaneous metal parts.
2) Other solvent-related regulations, including CTGs for graphic arts, metal degreasing, and drycleaners using perchloroethylene.
3) Petroleum-related regulations, including CTGs for bulk gasoline plants and terminals, liquids in fixed- and floating-roof tanks, miscellaneous sources in petroleum refineries, gasoline tank trucks, and delivery of gasoline to service stations.
4) Several additional regulations, including rubber tire manufacture, pharmaceutical manufacture, and cutback asphalt.

[8] EPA issued the following CTGs 1979 and later:
a) Regulations for large petroleum drycleaners.
b) Synthetic organic chemical industry (SOCMI) related regulations, including CTGs for high density plastic resins, air oxidation processes, volatile organic storage tanks, and leaks.
c) Regulations applying to leaks from natural gas and gas processing plants.

1) Areas with a design value less than 0.14 ppm that can attain by 1991:

  a) At least one of the following mobile-source related measures:

    1) Enhanced inspection and maintenance (I/M) program for highway vehicles in urban areas with more than 100,000 people.

    2) "Stage II" control devices on gasoline pumps to capture emissions during refueling.

    3) Use of alternative fuels by centrally-fueled fleets with 50 or more vehicles.

  b) RACT for both VOC and NO_x on stationary sources emitting greater than 25 tons per year.

  c) LAER for both VOC and NO_x for new stationary sources emitting more than 25 tons per year or modified stationary sources emitting more than 10 tons per year.

  d) "Such other measures as may be necessary to provide for attainment".

2) Areas that can attain by 1993:

All of the measures listed in 1) above, including *all three* mobile-source related measures.

3) Areas that choose a deadline later than 1993:

All of the measures listed in 1) above (including all three mobile-source related measures), plus:

  a) Adoption of "transportation control measures" (TCMs) to offset growth in vehicle miles traveled (VMT), or emissions associated with increases in VMT.

  b) Area-wide emissions reductions (below the 1987 base) of both VOC and NO_x:

33 percent by 1992,
50 percent by 1995,
65 percent by 1998.

  c) Each stationary source emitting more than 25 tons per year of VOC or NO_x must achieve reductions of both pollutants from 1987 levels at least equal to the area-wide requirement.

4) Areas with a design value of 0.27 ppm or greater:

All of the measures listed in 3) above, plus, in each 3 year period after 1998 until attainment, an additional 15 percent area-wide emission reduction (below the 1987 base) of both VOC and NO_x.

5) Areas that cannot demonstrate attainment by 2003:

All of the measures listed in 4) above plus:

a) Adoption of transportation control measures to assure that passenger vehicle occupancy on highways exceeds 1.5 people per vehicle.

b) Emission standards for off-highway vehicles at least as stringent as those in effect for cars.

c) By 1998, 15 percent, and by 2003, 40 percent, of motor vehicles must be able to use alternative fuels.

d) Commercial and residential sources of VOC and NO_x emitting more than one ton per year must reduce emissions to the maximum extent possible.

The Senate Environment Committee proposal requires EPA to issue the following CTGs:

1) Within two years of enactment, EPA must issue CTGs for sources emitting more than 25 tons per year of VOC or NO_x, for the following 11 source categories:

Wood furniture coating; autobody refinishing; metal rolling; synthetic organic chemical industry (SOCMI) distillation; SOCMI batch process; hazardous waste treatment, storage, and disposal facilities; bakeries; sewage treatment plants; web offset lithography; plastic parts coating; and coke oven by-product plants.

2) Within four years of enactment, EPA is to revise all existing CTGs to be consistent with the bill's definition of "reasonably available control technology". These CTGs are to apply to sources emitting more than 25 tons per year of VOC or NO_x.

H.R.3054:

The Waxman bill creates three distinct categories of nonattainment areas, with the following State-implemented controls required:

1) Areas with a design value less than 0.144 ppm:

Annual percentage reduction in VOC and NO_x sufficient to attain the standard within 3 years, as calculated by EPA.

2) Areas with a design value between 0.144 and 0.18 ppm:

Annual percentage reduction in VOC and NO_x sufficient to attain the standard within 5 years, as calculated by EPA, plus:

a) Enhanced inspection and maintenance (I/M) program for highway vehicles in urban areas with more than 100,000 people.

b) LAER for both VOC and NO_x for new or modified stationary sources emitting greater than 25 tons per year.

3) Areas with a design value greater than 0.18 ppm:

Annual percentage reduction in VOC and NO_x sufficient to attain the standard within 10 years, as calculated by EPA, plus:

a) Enhanced inspection and maintenance (I/M) program for highway vehicles in urban areas with more than 100,000 people.

b) LAER for both VOC and NO_x for new or modified stationary sources emitting greater than 10 tons per year.

c) Fleets of 15 or more vehicles must be capable of using alternative fuels. By 1997, 30 percent of new motor vehicles must be able to use alternative fuels.

d) Catalytic control technology (or technology that achieves equivalent emission rates) on all oil- and coal-fired boilers.

The Waxman bill requires EPA to issue CTGs for the 12 categories of uncontrolled stationary sources that make the most significant contribution to ozone formation, in the judgment of the Administrator. EPA must promulgate 4 CTGs by 1988 and 2 CTGs per year for succeeding years. The CTGs are to apply to sources emitting more than 25 tons per year of VOC or NO_x.

EPA's post-1987 ozone policy:

The EPA proposal creates three distinct categories of nonattainment areas, with the following State-implemented controls required:

1) Areas with a design value less than 0.16 ppm and able to demonstrate attainment with federally implemented and existing control measures within about 6 years:

No new control requirements

2) Areas able to demonstrate attainment within about 6 years:

a) Enhanced inspection and maintenance (I/M) program for highway vehicles in urban areas with more than 200,000 people.

b) RACT for all stationary sources of VOC emitting greater than 100 tons per year (including those for which CTGs have not been issued), *unless* the State can convincingly demonstrate that not all controls will be required to reach attainment.

c) VOC emissions reductions of at least 3 percent per year below 1987 levels, not counting reductions from 1) federally implemented measures or 2) control requirements imposed prior to 1987.

3) Areas not able to demonstrate attainment within 6 years:

All of the measures listed in 2) above, with no exemptions for the requirement of RACT on major stationary sources.

Federally Implemented, Nationwide Control Requirements

In this section we review the nationwide controls required under current laws and regulations and summarize the changes and additions under the new proposals.

Current law and regulations include the following controls:

1) New source performance standards (NSPS) requiring the "best available control technology" on certain new stationary sources of VOC and NO_x.[9] (Note that the "lowest achievable emission rate" for VOC required for new sources in nonattainment areas can be more stringent than the nationwide NSPS controls.)

2) Tailpipe exhaust standards for passenger cars:

0.41 grams per mile (g/mi) hydrocarbon (HC) and 1.0 g/mi NO_x. Standards must be met for at least 5 years or 50,000 miles.

3) Tailpipe exhaust standards for light duty trucks:

a) 0.8 g/mi HC and 1.2 g/mi NO_x for trucks with gross vehicle weights up to 3750 lbs.

b) 0.8 g/mi HC and 1.7 g/mi NO_x for trucks with gross vehicle weights over 3750 lbs.

Standards must be met for 120,000 miles.

4) Tailpipe exhaust standards for heavy duty diesel engines:

a) 1.3 grams per brake-horsepower-hour (g/bhp-hr) HC and 10.7 g/bhp-hr NO_x.

b) 5.0 g/bhp-hr NO_x by model year 1991.

Standards must be maintained for 120,000 miles.

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[9] EPA has issued NSPS for the following VOC sources:
1) Surface coating regulations, including NSPS for coating large appliances, metal furniture, autos and light duty trucks, beverage cans, metal coils, magnetic tape, pressure sensitive tapes and labels, and flexible vinyl coating.
2) Petroleum-related regulations, including NSPS for petroleum refining, refinery wastewater, bulk gasoline terminals, storage vessels, and natural gas production.
3) Synthetic organic chemical industry (SOCMI) related reglations, including NSPS for air oxidation equipment, distillation operations, reactors and other equipment.
4) Others including NSPS for dry cleaning, graphic arts, synthetic fiber production, and rubber tire manufacture.

5) Limits on gasoline evaporation from highway vehicles.

S.1894:

The Senate Environment Committee proposal includes the following changes and additions to current laws and regulations:

1) Tailpipe exhaust standards for passenger cars and trucks under 6000 lbs:

   a) 0.25 g/mi HC by model year 1992.

   b) 0.4 g/mi NO_x by model year 1990.

   Pollution control equipment must be able to meet these standards for at least 10 years or 100,000 miles.

2) Tailpipe exhaust standards for light duty trucks:

   a) 0.5 g/mi HC by model year 1990.

   b) 0.5 g/mi NO_x by model year 1990.

   Light duty trucks are defined as those with gross vehicle weight (gvw) between 6000 and 8500 lbs and curb weight less than 6000 lbs. Trucks less than 6000 gvw are considered light duty vehicles.

3) NO_x exhaust standards for heavy duty vehicles:

   a) 4.0 grams per brake-horsepower-hour (g/bhp-hr) by model year 1991.

   b) 1.7 g/bhp-hr by model year 1995.

4) "Onboard" technology for cars and trucks to control refueling emissions by model year 1991.

5) Limit on the volatility (i.e., rate of evaporation) of gasoline sold during warm weather months of 9 lbs Reid Vapor Pressure (RVP) beginning in 1990.

6) Regulations for the following source types, promulgated by EPA within 2 years after enactment, to achieve the degree of control equivalent to adoption of reasonably available control technology (RACT): (1) commercial solvents, (2) consumer solvents, (3) architectural coatings, (4) pesticide application, (5) traffic-marking coatings, and (6) metal-parts coatings for military applications and aerospace- industry applications.

H.R.3054:

The Waxman bill includes the following changes and additions to current laws and regulations:

1) Tailpipe exhaust standards for passenger vehicles:

   a) 0.25 g/mi HC by model year 1992.

   b) 0.4 g/mi NO_x by model year 1990.

   Standards must be maintained for 50,000 miles.

2) Tailpipe exhaust standards for light duty trucks:

   a) 0.5 g/mi HC by model year 1990.

   b) 0.5 g/mi NO_x by model year 1990.

   Standards must be maintained for 120,000 miles.

3) NO_x exhaust standard for heavy duty trucks of 1.7 grams per brake-horsepower-hour (g/bhp-hr) by model year 1994.

4) "Onboard" technology for cars and trucks to control refueling emissions by model year 1990.

5) Limit on the volatility (i.e., rate of evaporation) of gasoline sold between May 16 and September 15 of 10.5 lbs Reid Vapor Pressure (RVP) beginning in 1990, 9.0 lbs RVP beginning in 1993.

6) Regulations to achieve the lowest feasible emission rate for the following source types, promulgated by EPA by 1990: commercial and consumer solvents, architectural coatings, pesticide application, traffic-marking coatings, and metals-parts coatings in military applications.

EPA's post-1987 ozone policy:

EPA has proposed the following changes and additions to current laws and regulations:

1) Tailpipe exhaust standards for light duty trucks:

   a) 0.41 g/mi HC for trucks weighing less than 6000 lbs gvw.

   b) 0.5 g/mi HC for light duty trucks weighing 6000 lbs gvw or greater.

   (Advanced notice of proposed rulemaking published September 1986.)

2) "Onboard" technology for cars and trucks to control refueling emissions by model year 1990. (Notice of proposed rulemaking published August 1987.)

3) Limits on the volatility (i.e., rate of evaporation) of gasoline sold between May 16 and September 15 of 10.5 lbs Reid Vapor Pressure (RVP) beginning in 1990, and 9.0 lbs RVP beginning in 1993. (Notice of proposed rulemaking published August 1987.)

Transport Regions

Both ozone and its precursors, VOC and NO_x, can be transported from upwind areas into nonattainment regions downwind. Thus, some fraction of the ozone found in nonattainment areas is not subject to local regulatory authority. If the upwind area is also a nonattainment region, at least some further control will take place to bring the area into attainment with the standard. However, if the upwind region already meets the standard, no further control can be expected. Current law does not provide an adequate mechanism to implement controls in areas that currently attain the standard, but contribute to ozone nonattainment problems in areas downwind.

To address this problem, both S.1894 and H.R.3054 establish multi-state "ozone transport regions". Controls are required throughout these multi-state regions, regardless of attainment status. Both bills establish a transport region along the Northeast corridor from Maine to Virginia; S.1894 establishes a second one in the Midwest. Though the EPA proposal identifies the Northeast corridor as a region where multi-day transport occurs, no additional control requirements are proposed.

Discussions of each of the new proposals follow:

S.1894:

The bill establishes two "ozone transport regions": one along the Eastern seaboard from Maine to the northern half of Virginia, plus Vermont, New Hampshire, Pennsylvania and Ohio; the second, which includes Illinois, Indiana, Michigan, and Wisconsin. The Administrator may add States to these regions or create additional regions.

The bill requires:

1) Enhanced inspection and maintenance (I/M) program for highway vehicles in urban areas with more than 125,000 people.

2) RACT on stationary sources for which EPA has published CTG's prior to enactment.

A commission of Governors and EPA officials is established to make decisions about additional controls, which must be adopted by all States in the transport region if voted for by a majority of the commission.

H.R.3054:

The bill establishes one "ozone transport region" along the Eastern seaboard from Maine to Virginia, plus Vermont, New Hampshire, and Pennsylvania. The Administrator may add States to this region or create additional regions. Individual counties, air quality control regions (AQCRs), or States may be exempted from control requirements if they do not significantly contribute to other region's nonattainment problems. Either the Administrator or a commission of EPA and State air pollution control officials can exempt areas.

Specific control requirements for ozone transport regions are the same as those mandated for areas with design values between 0.144 and 0.18 ppm:

1) Enhanced inspection and maintenance (I/M) program for highway vehicles in urban areas with more than 100,000 people.

2) LAER for both VOC and NO_x for new or modified stationary sources emitting greater than 25 tons per year.

3) It is unclear whether the Administrator can specify additional reductions in VOC and NO_x, and if so, whether the Administrator or the commission decides which source categories are to control emissions.

EPA's post-1987 ozone policy:

EPA will require that planning areas cover entire metropolitan areas (MSAs or CMSAs) to address single-day transport problems. EPA identifies the Northeast corridor as the only region where multi-day transport is a problem. No special requirements for this region are proposed.

Controls On Emissions Of Nitrogen Oxides

Ozone is produced via chemical reactions of both VOC and NO_x. In the past, EPA has encouraged exclusive reliance on control of VOC emissions to achieve compliance with the ambient air quality standard for ozone. Only California has mandated controls of both VOC and NO_x emissions.

In Section 3.1, we discussed the site-specific situations under which NO_x controls would lower ozone concentrations and the situations where NO_x controls might be counterproductive. Combined VOC and NO_x controls will result in lower ozone concentrations than VOC controls alone in many cities. However, in some cities, for example, Baltimore, Boston, Philadelphia, and Washington, combined controls may lead to higher ozone concentrations in some locations within the urban area than would VOC reductions alone. Further complicating the decision about whether to mandate NO_x controls is the expectation that while NO_x controls might be counterproductive for some locations within the urban area, they might lower ozone concentrations in the next city downwind.

Each of the three proposals includes NO_x controls to some degree, and with varying degrees of flexibility. The Senate Environment Committee proposal requires NO_x reductions from both existing and new sources in all nonattainment areas. The Waxman bill requires some NO_x control, but not as much as the Senate proposal. Control of new sources of NO_x is required; the extent to which existing sources of NO_x must be controlled is left to EPA to decide. The EPA proposal allows States to supplement VOC controls with NO_x controls, and in some cases substitute NO_x controls for VOC, but does not require NO_x controls.

Discussions of each of the new proposals follow:

S.1894:

The Senate Environment Committee proposal applies controls about equally to sources of both NO_x and VOC. Requirements for reasonably available control technology (RACT) on major stationary sources apply to both VOC and NO_x in nonattainment areas (but to VOC alone in attainment areas in transport regions). Percentage reduction requirements for nonattainment areas that cannot attain the standard before 1993 are identical for both pollutants, as are most other requirements of the bill. NO_x emission standards for new cars and trucks are lowered.

In addition, Title II, the portion of the bill that addresses acid deposition, establishes a Statewide maximum emission rate on NO_x from fossil-fuel fired boilers.

H.R.3054:

The Waxman bill deals with NO_x control in the following way:

1) For all nonattainment areas, the Administrator of EPA must specify the percentage reduction of both VOC and NO_x needed to meet the standard by the assigned deadline. Thus the decision of whether to rely on VOC controls alone or combined VOC/NO_x control from existing sources is left to EPA.

2) In nonattainment areas with design values greater than 0.144 ppm, new source controls are required on new and modified stationary sources of NO_x above 25 tons per year.

3) In nonattainment areas with design values greater than 0.18 ppm:

   a) New source controls are required on new and modified stationary sources of NO_x above 10 tons per year.

   b) Catalytic technology for the control of NO_x emissions (or a technology that achieves equivalent emission rates) is required for all oil- and coal-fired boilers.

4) NO_x emission standards for new cars and trucks are lowered.

5) EPA must issue control technique guidelines for 12 categories of uncontrolled stationary sources. The guidelines are to apply to VOC, NO_x, or both, at the discretion of the Administrator.

EPA's post-1987 ozone policy:

The EPA proposal requires some nonattainment areas (those with high ratios of VOC to NO_x in the ambient air) to evaluate the effectiveness of NO_x reductions. In those nonattainment areas where a State determines that NO_x controls will be beneficial, NO_x controls may be used in addition to VOC controls to satisfy the EPA requirements for "reasonable progress" towards attainment. However, while NO_x controls can supplement VOC controls, they cannot be used to avoid VOC controls on major stationary sources, unless the likelihood of attainment is demonstrated by rigorous air quality modeling.

Long-Term Strategies

Even though most of the requirements listed below have already been presented in earlier sections of this chapter, in this section we highlight the requirements that will help attain or maintain the standard over the long-term. These include such components as more stringent emission standards for gasoline- and diesel-fueled motor vehicles, use of alternatively fueled motor vehicles, and strategies to prevent growth in emissions from stationary sources.

As discussed in Chapter 3, even after applying all near-term control measures OTA was able to analyze, many areas will still not attain the standard. Thus, while many areas' ozone nonattainment problems may be remedied in about five years, for many others, ozone nonattainment may remain as a chronic problem for at least a decade. For such areas, two issues must be addressed: 1) additional controls must be identified, some of which (like new motor vehicle controls or use of alternative fuels) may take a decade or more to take effect and 2) steps must be taken to offset emissions increases due to population and economic growth.

The proposals include the following long-term strategies to address ozone nonattainment problems over the next decade or two:

S.1894:

The Senate Environment Committee proposal requires:

1) SIPs must address maintenance of the standard for 20 years after enactment.

2) New stationary sources in nonattainment areas emitting more than 25 tons per year and modified stationary sources emitting more than 10 tons per year must achieve the "lowest achievable emission rate" (LAER). The current cutoffs for most nonattainment areas are 100 tons per year for new sources and 40 tons per year for modified sources.

3) Use of alternative fuels for centrally fueled fleets of 50 or more vehicles.

4) tighter emission standards for cars and trucks.

5) In areas that choose an attainment deadline past 1993:

   a) Each ton of emissions increases from new or modified major stationary sources must be offset by 2 tons of reductions from other sources in the nonattainment area.

   b) Growth in vehicle miles traveled (VMT), or emissions associated with VMT growth, must be offset.

6) In areas that cannot demonstrate attainment by 2003:

All of the measures listed in 5) above plus:

   a) Adoption of transportation control measures to assure that passenger vehicle occupancy on highways exceeds 1.5 people per vehicle.

   b) By 1998, 15 percent, and by 2003, 40 percent, of motor vehicles must be able to use alternative fuels.

H.R.3054:

The Waxman bill requires:

1) SIPs to include plans for maintaining the standard.

2) tighter emission standards for cars and trucks.

3) In nonattainment areas with a design value greater than 0.144 ppm, new or modified stationary sources in nonattainment areas emitting greater than 25 tons per year are subject to new source control requirements. The current cutoffs for most nonattainment areas are 100 tons per year for new sources and 40 tons per year for modified sources. Each ton of emissions increases from new or modified major stationary sources must be offset by reductions of 1.2 tons from other sources.

4) In nonattainment areas with design value greater than 0.18 ppm:

   a) New or modified stationary sources in nonattainment areas emitting greater than 10 tons per year are subject to new source control requirements. Each ton of emissions increases from new or modified major stationary sources must be offset by reductions of 1.5 tons.

b) Fleets of 15 or more vehicles must be capable of using alternative fuels. By 1997, 30 percent of new motor vehicles must be able to use alternative fuels.

c) All new boilers must use catalytic control technology (or equivalent) or burn natural gas, methanol, or ethanol.

EPA's post-1987 ozone policy:

Under EPA's proposed ozone policy:

1) To be redesignated as an attainment area, a State must project emissions and detail control requirements for 10 years after attainment.

2) Under current regulations, new stationary sources in nonattainment areas emitting greater than 100 tons per year and modified stationary sources emitting greater than 40 tons per year must achieve the "lowest achievable emission rate" (LAER). Emissions must either be directly offset with decreases at other sources or the State must adopt a strategy to provide "growth accommodation" by controlling beyond federally prescribed measures and other measures needed to show "reasonable further progress".

Appendix A. Assumptions Used to Calculate Volatile Organic Compound Emissions Reduction Potential and Associated Costs of Control

Control Strategy[a]/ Source Description	Control Technique	Control Efficiency (%)	COST-EFFECTIVENESS:[b]		
			Small ($/ton)	Medium ($/ton)	Large ($/ton)
RACT:					
Solvent metal cleaning: large source[c]	Carbon adsorber	54	(288)	(488)	(569)
small source[c]	Carbon adsorber	83	17	17	17
Printing and publishing: large source	Carbon adsorber	85	722	270	26
small source	Carbon adsorber	85	(24)	(24)	(24)
Dry cleaning: large source	Recovery dryers	70	231	(60)	(259)
small source	Recovery dryers	70	3,573	3,573	3,573
Fixed roof tanks-crude oil	Internal floating roof	98	32	(113)	(172)
Fixed roof tanks-gasoline	Internal floating roof	96	(157)	(244)	(279)
External floating roof tanks-crude oil	Secondary seal	90	6,222	8,762	12,025
External floating roof tanks-gasoline	Secondary seal	95	266	631	1,188
Bulk gasoline terminals-splash loading	Submerged load, balanced service carbon absorb, truck test	91	1,639	302	(71)
Bulk gasoline terminals-submerged loading, balanced service	Carbon adsorb, truck test	87	316	(107)	(178)
Bulk gasoline terminals-submerged loading, not balanced	Balanced serv, truck test	79	460	(63)	(241)
Service stations-Stage I	Vapor balance	95	14	14	14
Ethylene oxide manufacture	Incinerator	98	344	331	314
Phenol manufacture	Incinerator	98	1,735	1,351	1,122
Terephthalic acid manufacture	Incinerator	98	942	924	895
Acrylonitrile manufacture	Incinerator	98	210	193	189
SOCMI fugitives	Equipment & maintenance	37	355	89	24
Petroleum refinery fugitives	Equipment & maintenance	69	(28)	(145)	(191)
Cellulose acetate manufacture	Carbon adsorber	72	6,198	2,093	(54)
Styrene-butadiene rubber manufacture	Incinerator	20	1,647	454	137
Polypropylene manufacture	Flare	98	218	60	18
Polyethylene manufacture	Flare	98	267	74	22
Ethylene manufacture	Flare	98	57	36	25
Petroleum refinery wastewater separators	Firebox covers	95	(139)	(153)	(159)
Petroleum refinery vacuum distillation	Firebox piping	100	53	15	3
Vegetable oil processing	Stripper & equipment	42	662	62	(270)
Paint and varnish manufacture	Afterburner	92	492	258	196
Rubber and plastics manufacture[d]	Carbon adsorber	83	566	566	566
Rubber tire manufacture	Carbon adsorber	83	1,569	830	(45)
Green tire spray	Solvent change	90	4	3	2
Carbon black manufacture	Flare	90	2,634	1,049	727
Automobile surface coating	Higher solids coating	88	5,176	6,648	9,146
Beverage can surface coating	Incinerator	57	2,348	1,227	628
General surface coating	Process change	70	810	602	436
Paper surface coating (large source)	Incinerator	90	492	(58)	(204)
(small source)	Incinerator	91	4,277	4,277	4,277
Miscellaneous surface coating	Incinerator	90	3,549	1,837	1,094
Misc. (includes: industrial solvent use and miscellaneous surface coating)[d]	Incinerator	75	7,722	7,722	7,722

Appendix A (continued).

		Control	COST-EFFECTIVENESS:[b]		
Category Name	Control Technique	Efficiency (%)	Small ($/ton)	Medium ($/ton)	Large ($/ton)
New CTG's:					
Plastic parts coating		90	2,000[e]	2,000	2,000
Wood furnitdure coating		90	2,000[e]	2,000	2,000
Coke-oven by-product plants		90	2,000[e]	2,000	2,000
Automobile refinishing	Incinerator	75	7,722	7,722	7,722
Federal Controls:					
Architectural surface coating[d]	Water-base coating	25	1,000[e]	1,000	1,000
Commerical and consumer solvent use[d]		90	2,000[e]	2,000	2,000
Stage II:[d]	Vapor balance	86	1,000[e]	1,000	1,000

(Derived from: Battye et al., Alliance Technologies Corporation, "Cost Assessment of Alternative National Ambient Air Quality Standards For Ozone, Draft Report," prepared for the U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Contract No. 68-02-4317, October 1987.)

[a] Strategy Descriptions

RACT = "Reasonable Available Control Technology" on all existing stationary sources that emit more than 25 tons per year of VOC.
New CTG's = new Control Technique Guidelines for existing stationary sources that emit more than 25 tons per year of VOC.
Federal Controls on selected small stationary sources of VOC (consumer and commercial solvents, and architectural surface coatings).
Stage II control devices on gas pumps to capture gasoline vapor during motor vehicle refueling.

[b] In our analysis, the cost-effectiveness for sources that emit greater than 50 tons per year of VOC was assumed to vary with changing source size. For sources emitting less than 50 tons per year, we assumed that cost-effectiveness does not change with source size. "Small", "Medium", and "Large" refers to cost-effectiveness for a typical source in these size ranges. Numbers inside parentheses denote a cost savings.

[c] "Large sources" emit more than 50 tons per year of VOC.
"Small sources" emit less than 50 tons per year of VOC.

[d] Sources that emit less than 50 tons per year of VOC.

[e] Cost-effectiveness assumed by OTA.